

Evaporation of Hot Jupiters

Observations & Models

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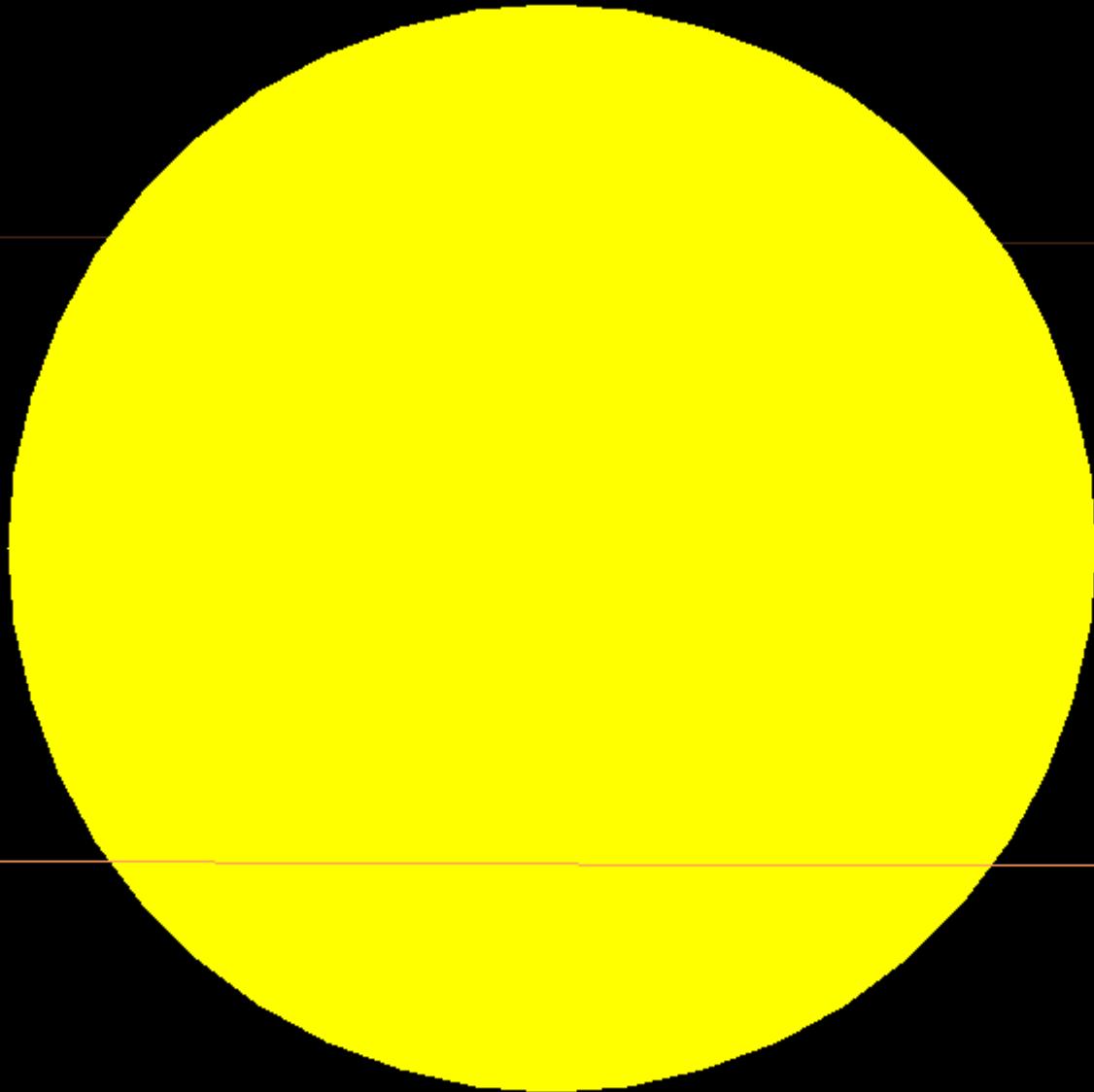
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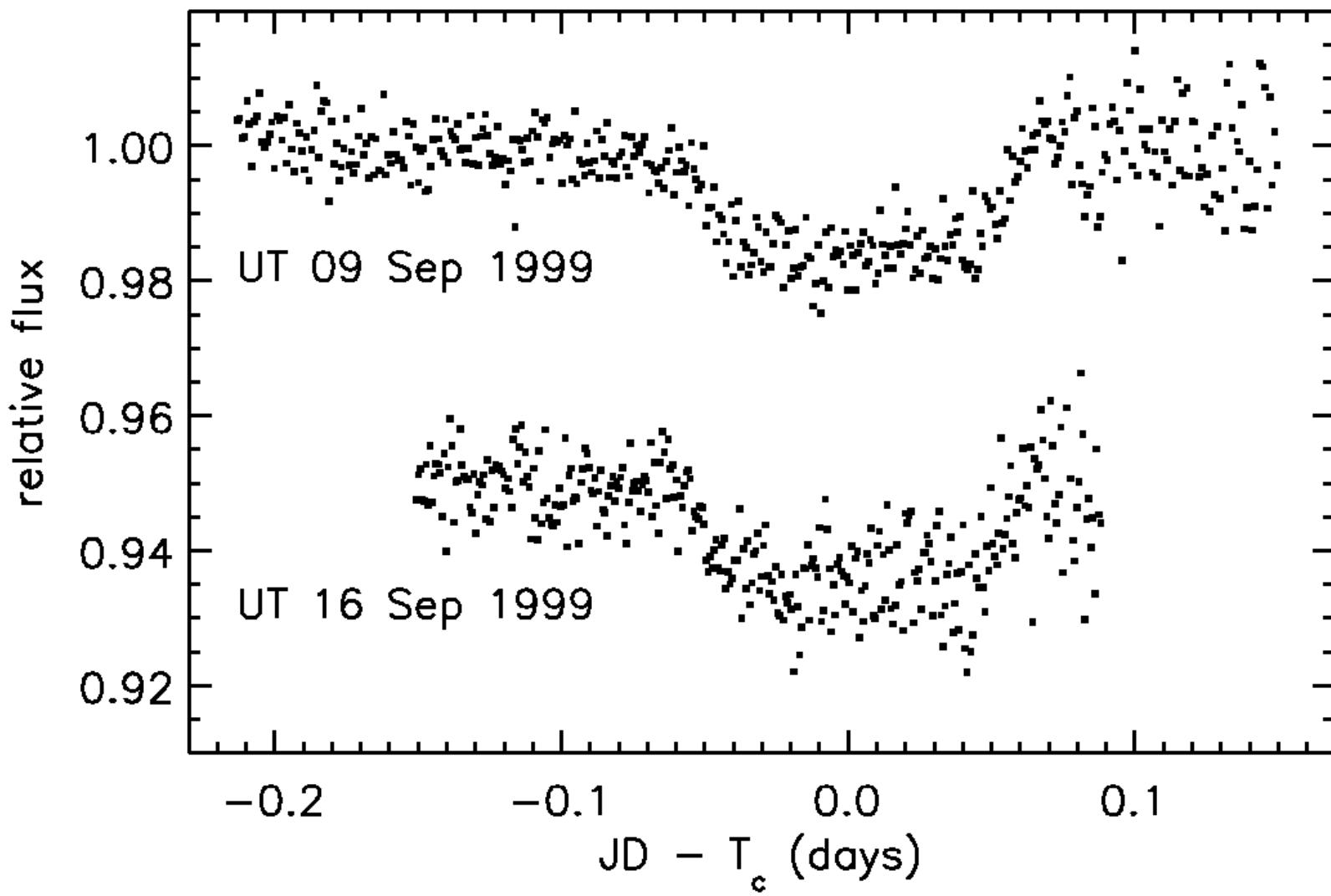
Alain Lecavelier des Etangs
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Alfred Vidal-Madjar
Jean-Michel Désert
Roger Ferlet
Guillaume Hébrard
(IAP, Paris)



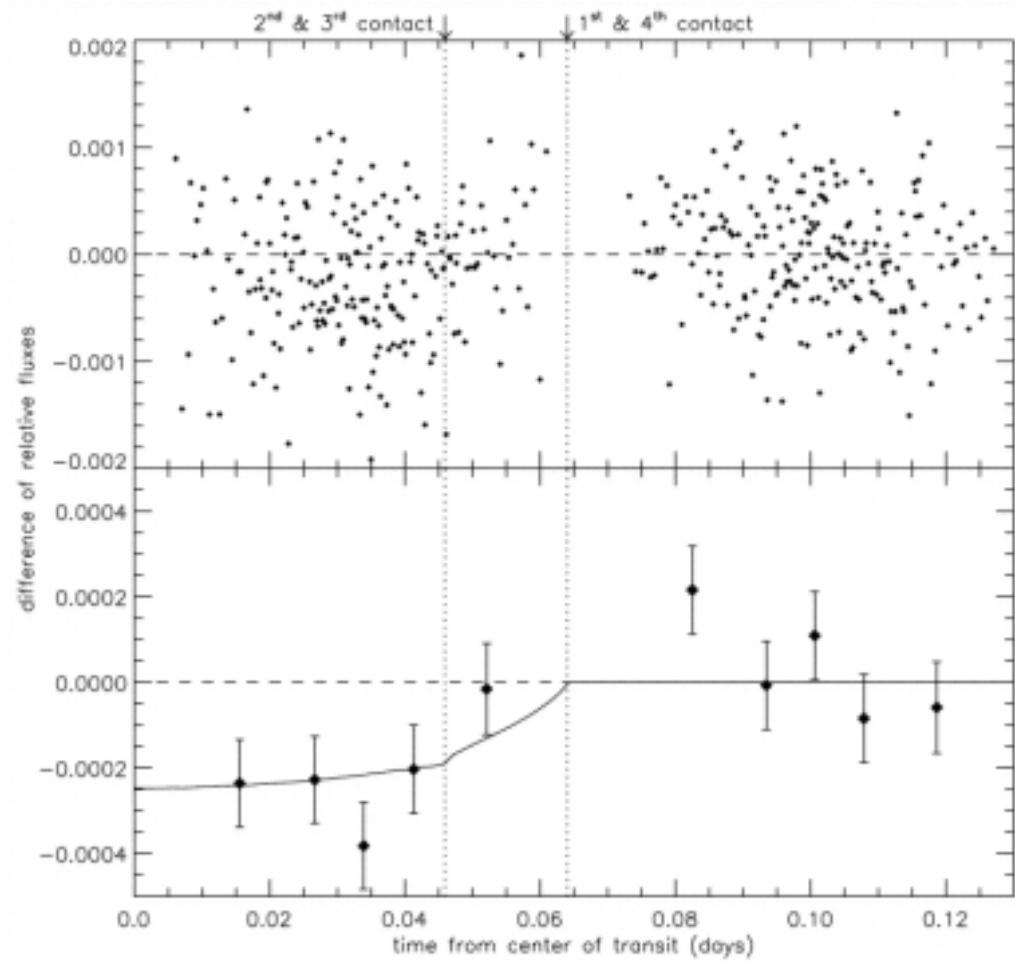
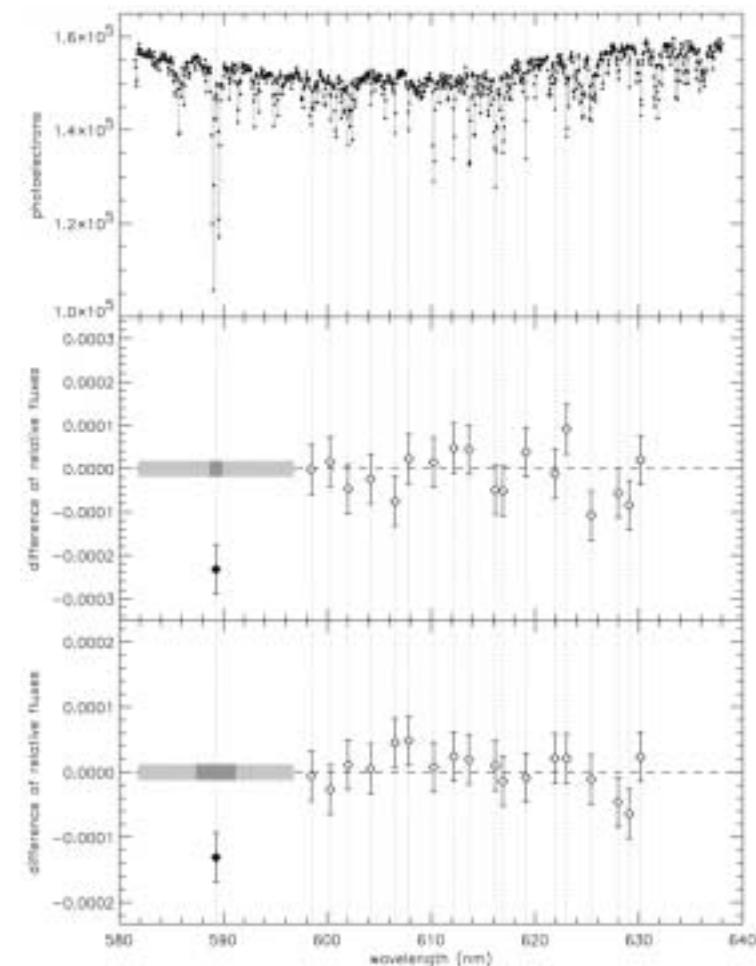
HD 209458b transit

(Charbonneau et al. 2000)



HD 209458b: Detection of the atmosphere in NaI

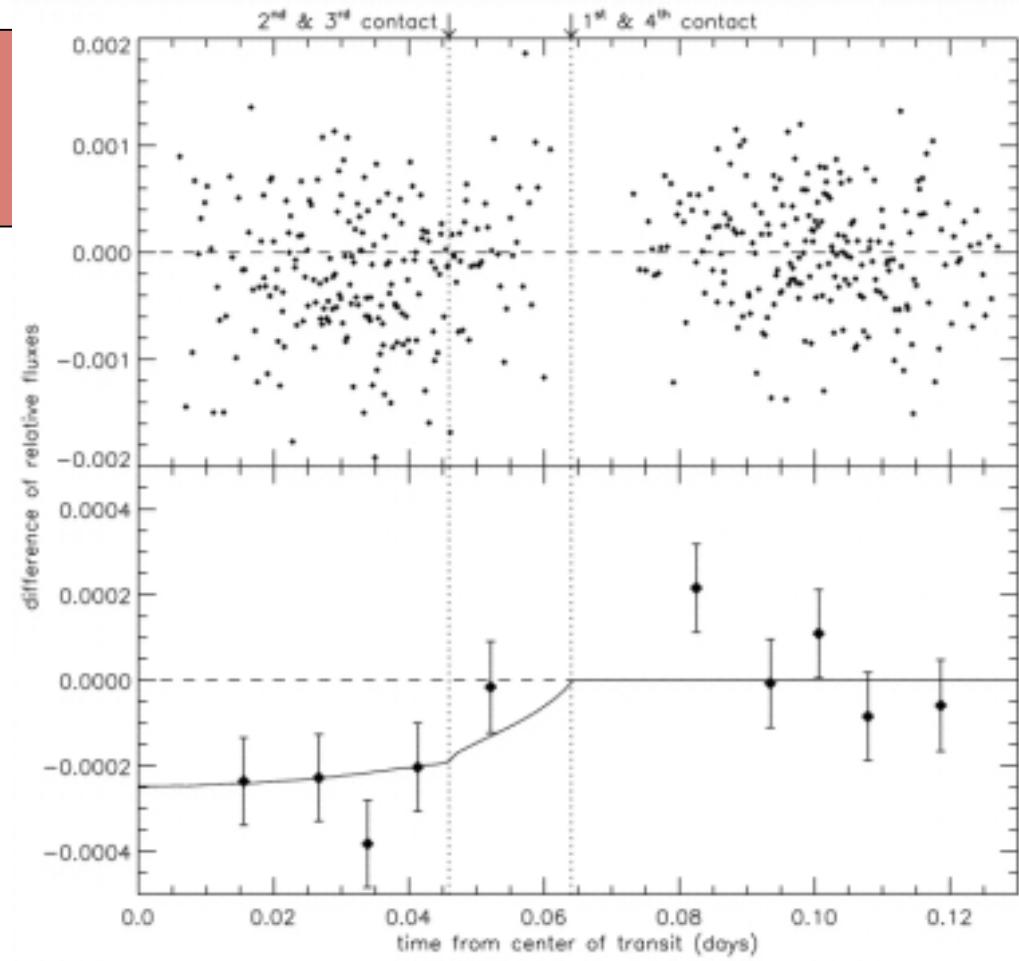
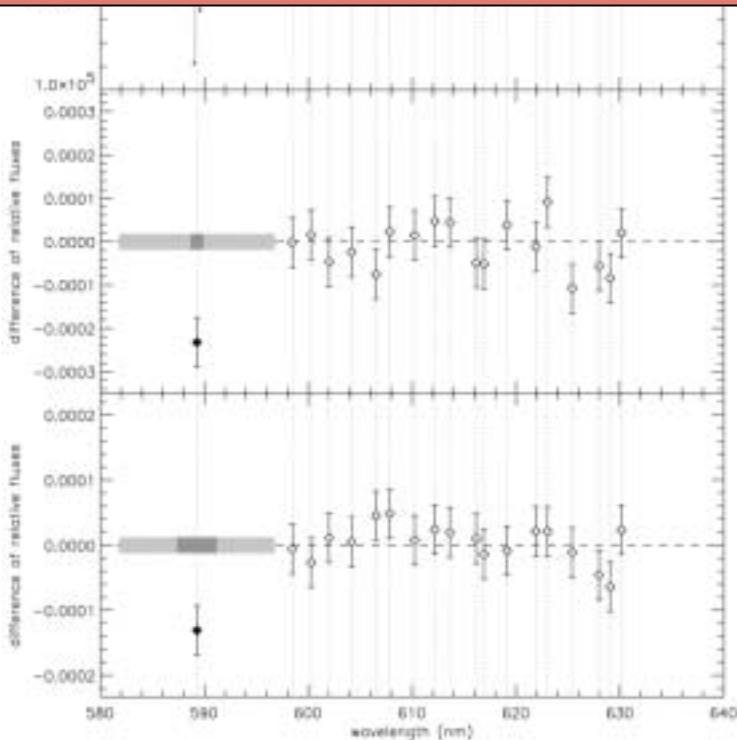
(Charbonneau et al. 2002)

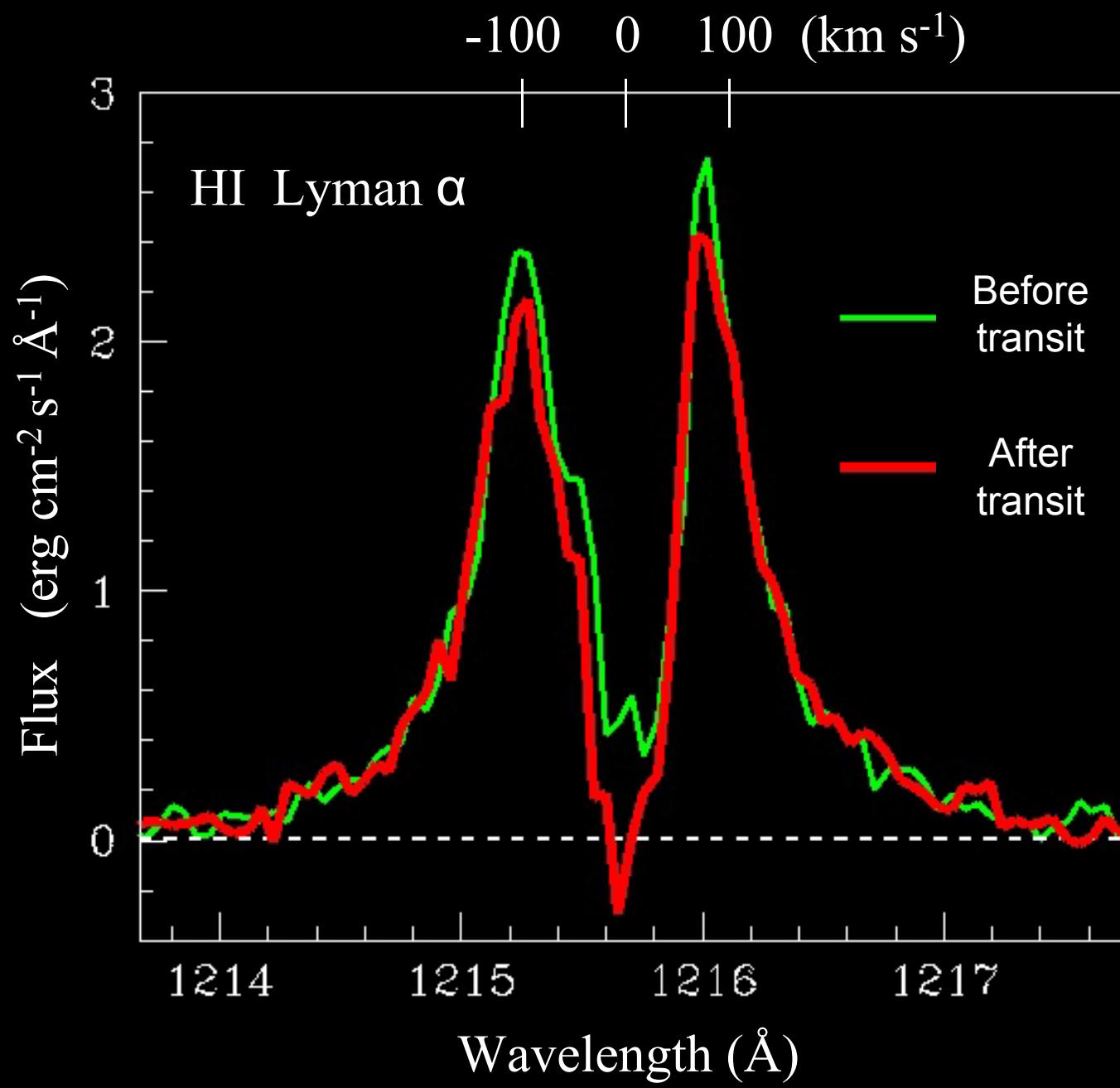


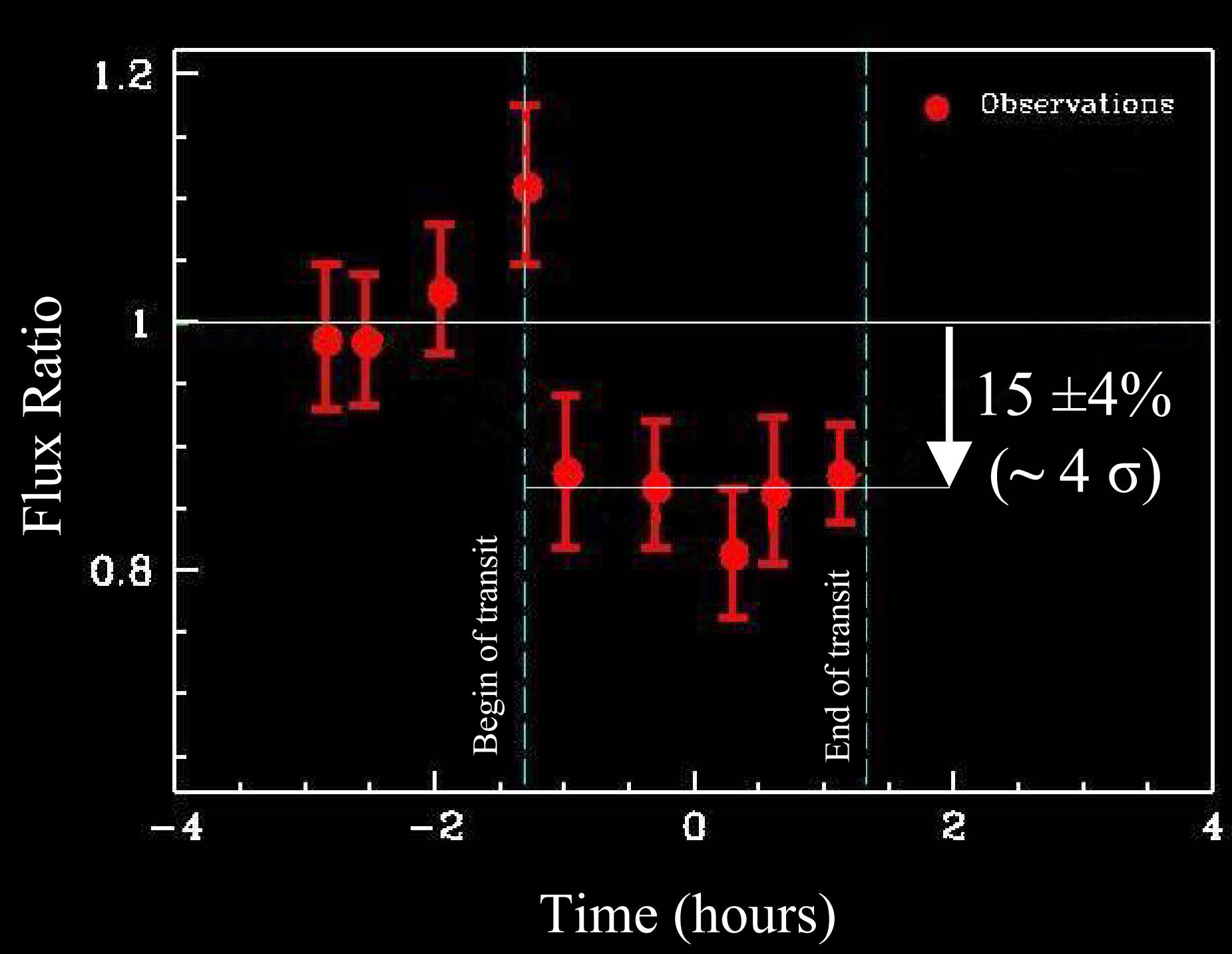
HD 209458b: Detection of the atmosphere in NaI

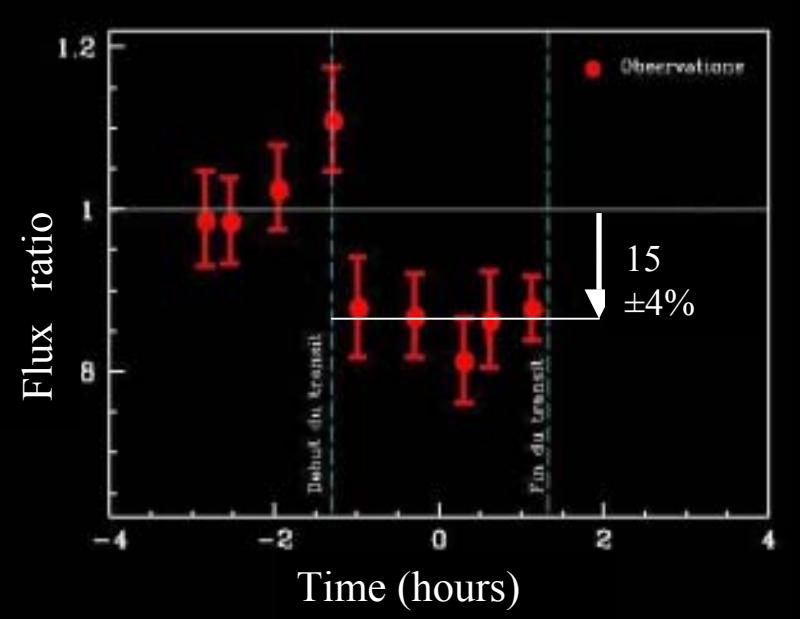
(Charbonneau et al. 2002)

$$0.0232 \pm 0.0057 \%$$

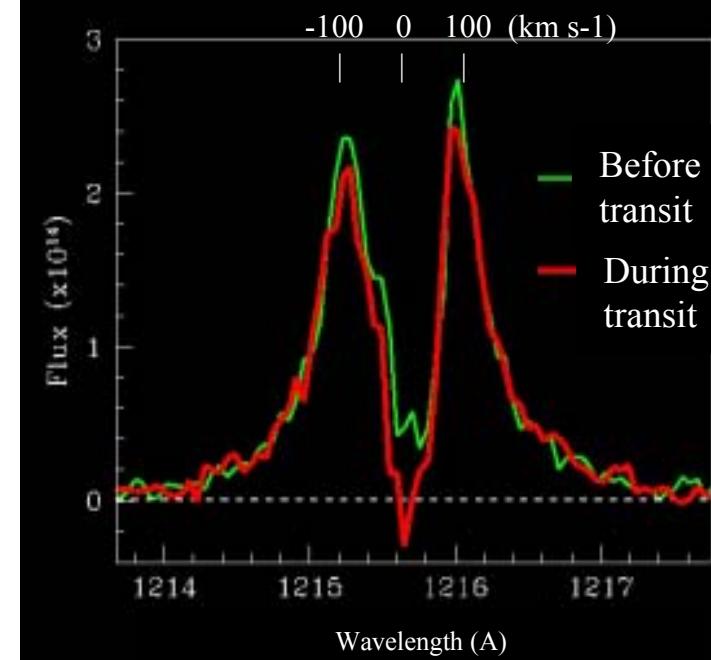








2 constraints:



- HD209458b ($1.35 R_{\text{Jupiter}} = 96,500 \text{ km}$)
Roche Lobe ($2.7 R_{\text{planet}} = 3.6 R_{\text{Jupiter}}$)
Hydrogen: **15 % absorption** → $3.2 R_{\text{planet}} = 4.3 R_{\text{Jupiter}} = 300\,000 \text{ km}$
→ Beyond the Roche Lobe → **Hydrogen is escaping**
 - Absorption width: $V_{\text{red}} \leq -100 \text{ km/s}$
 $V_{\text{esc}} = 54 \text{ km/s}$
→ Beyond escape velocity → **Hydrogen is escaping**
- The planet is evaporating



Escape rate estimate. *How much for 15% absorption?*

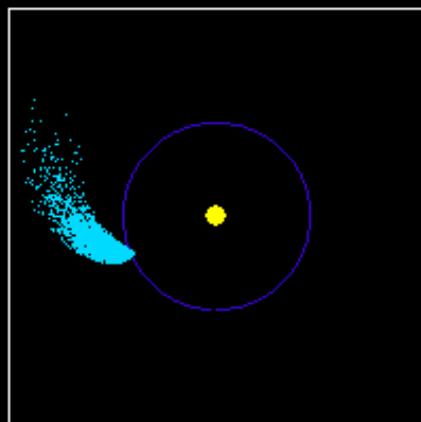
Particle simulation

- Radiation pressure: $\beta=0.7$
- Star and planet gravity are taken into account
- Free parameters:
 - HI volume density at the exobase:
(at $r \sim 0.5xR_{\text{Roche}}$: $2 \times 10^5 \text{ cm}^{-3}$)
 - Life time of HI: few hours ($\sim 6 \text{ h}$)

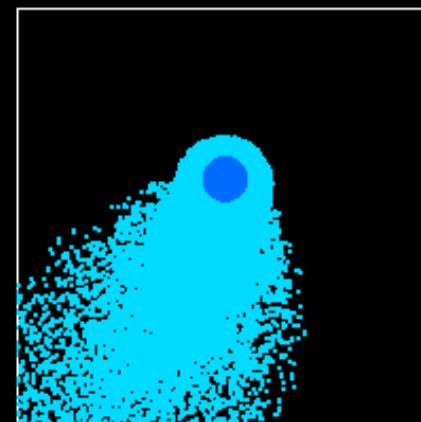
→ **Escape rate $> 10^{10} \text{ g/s}$**

Escape rate estimate. *How much for 15% absorption?*

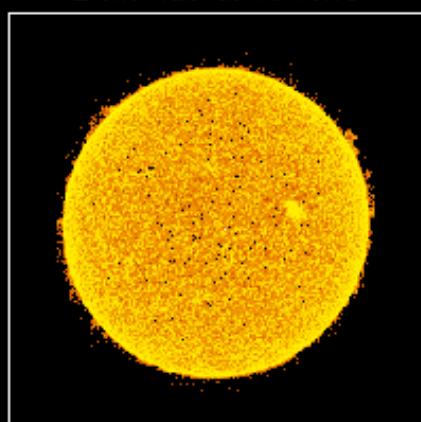
Système Etoile-Planète vu de dessus



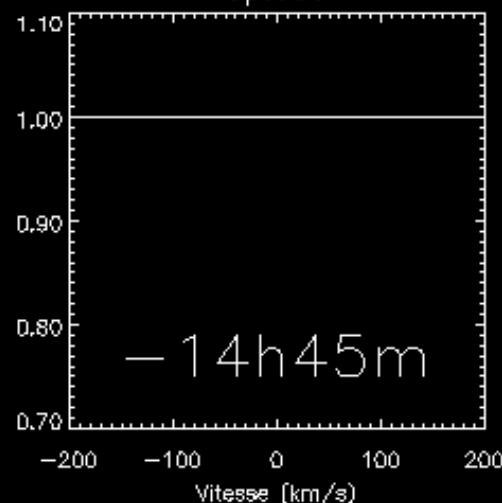
Planète vue de dessus



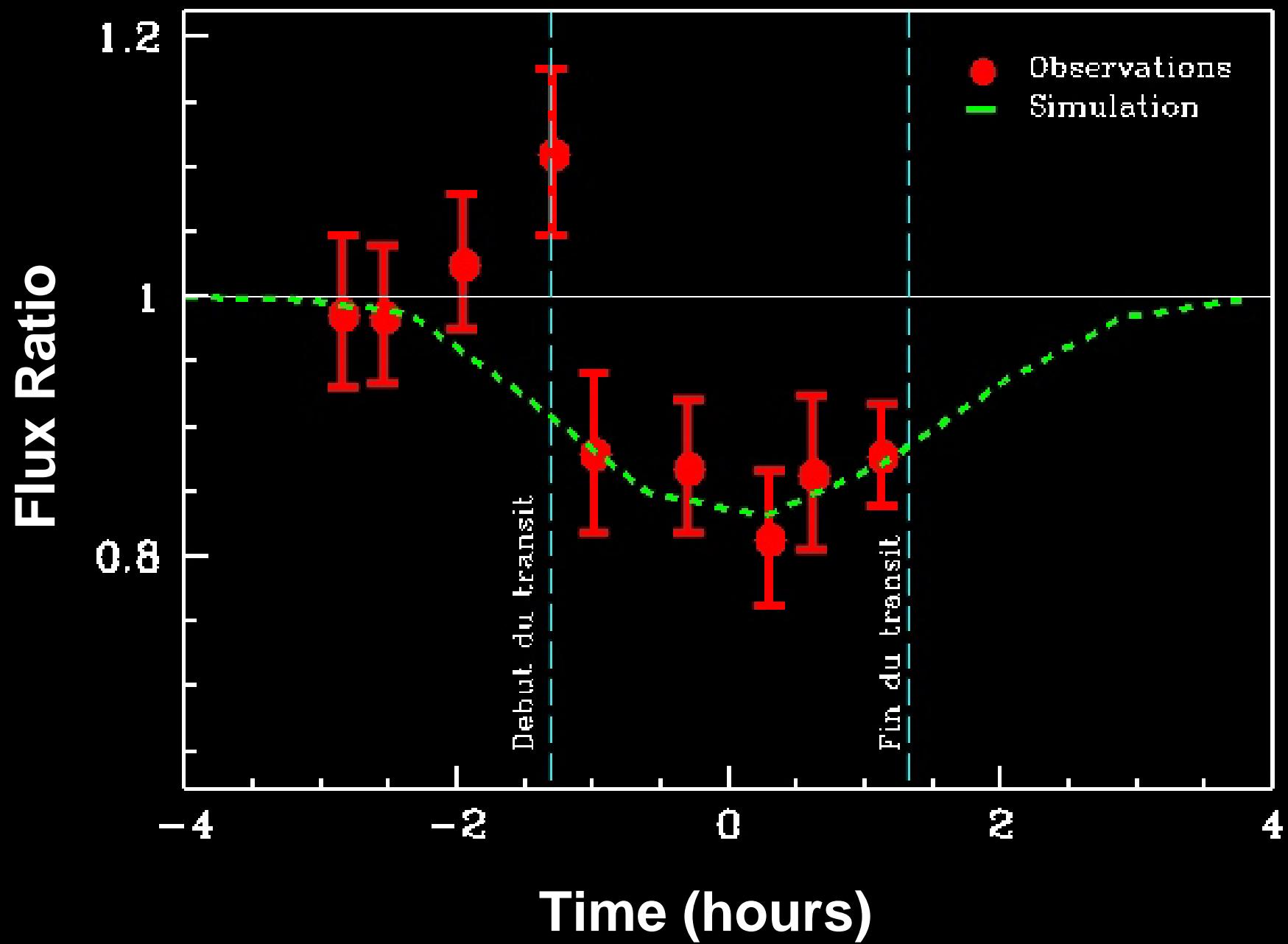
Etoile vue de la Terre



Spectre



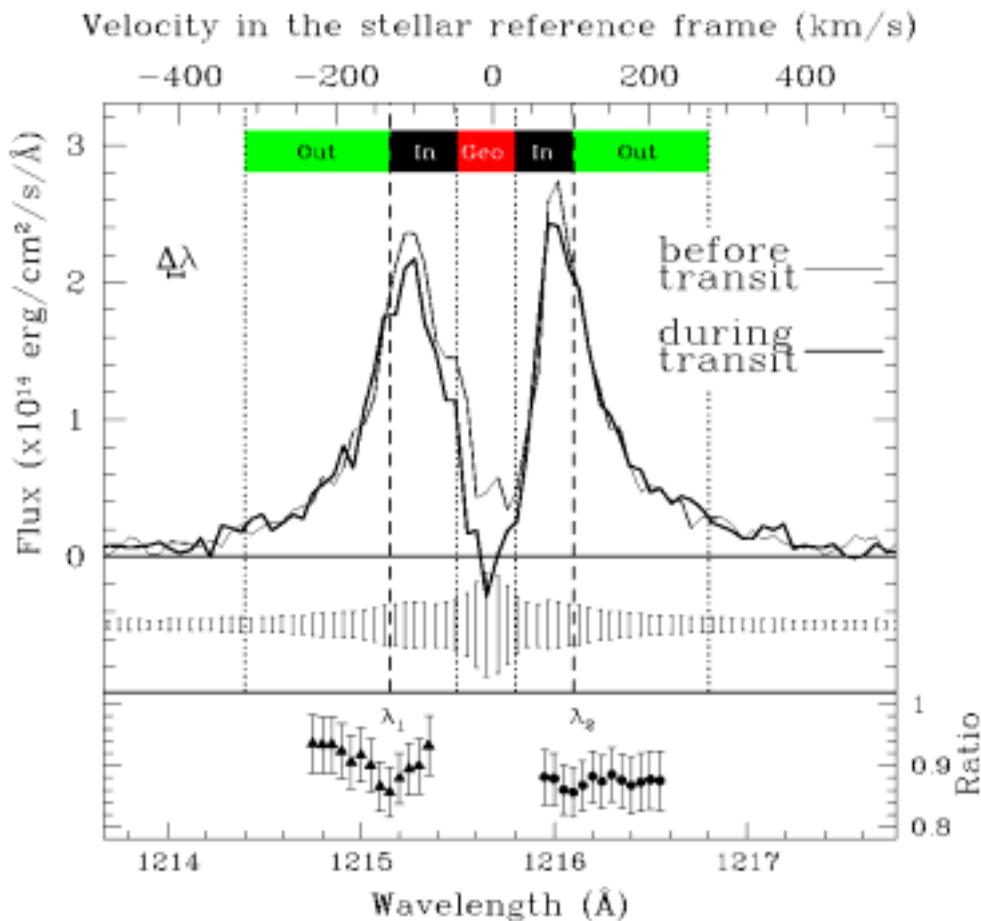
Escape rate $> 10^{10}$ g/s

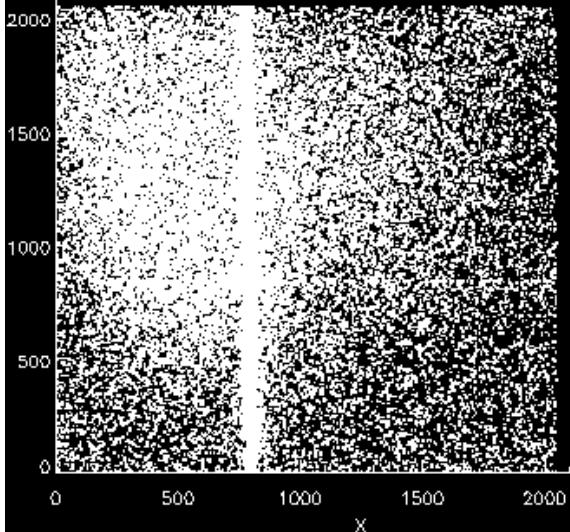


An extended upper atmosphere around the extrasolar planet HD209458b

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G. E. Ballester (Univ. Arizona)
R. Ferlet (IAP)
G. Hébrard (IAP)
M. Mayor (Obs. Genève)

Nature 422, 143 (13 March 2003)





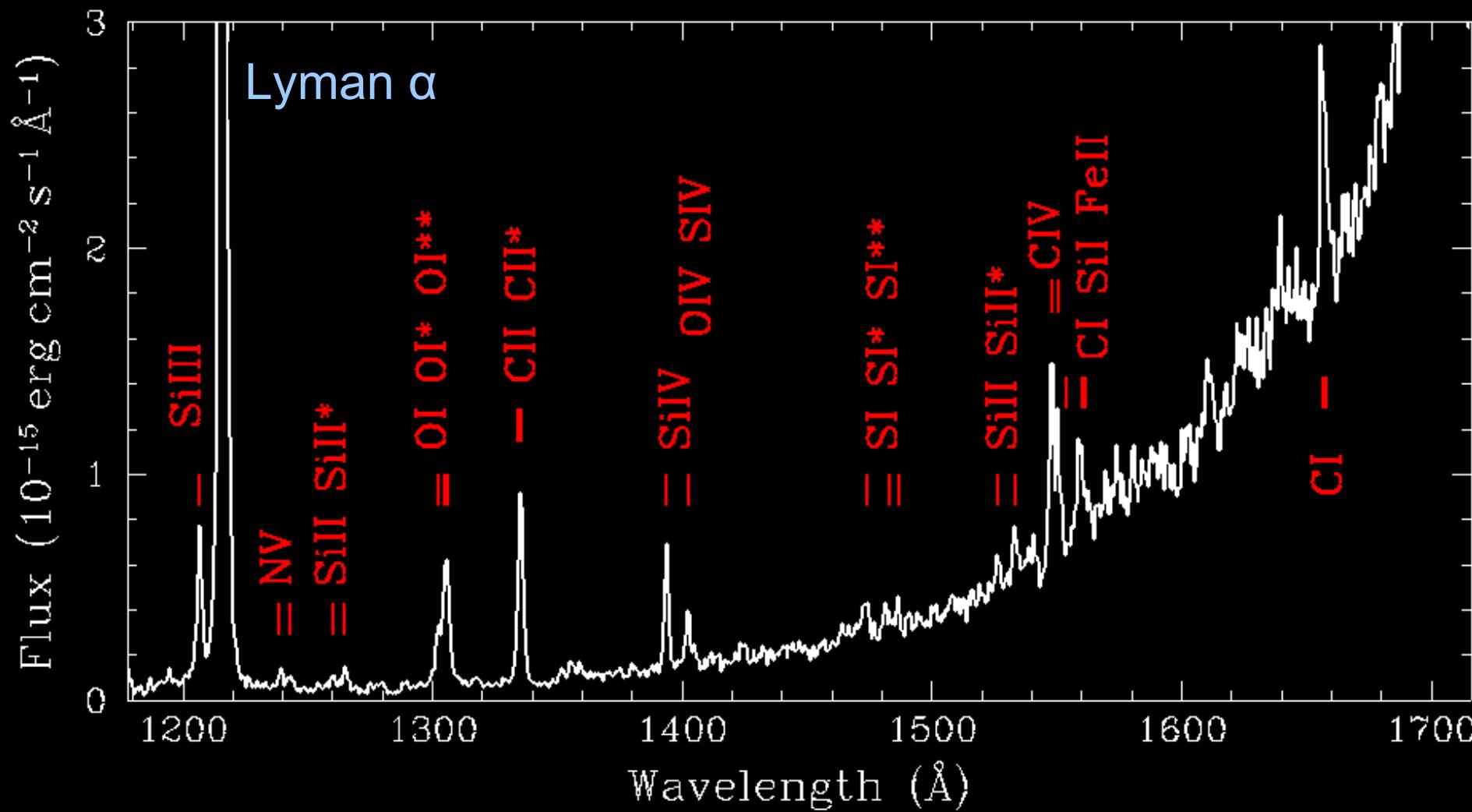
Number of photons

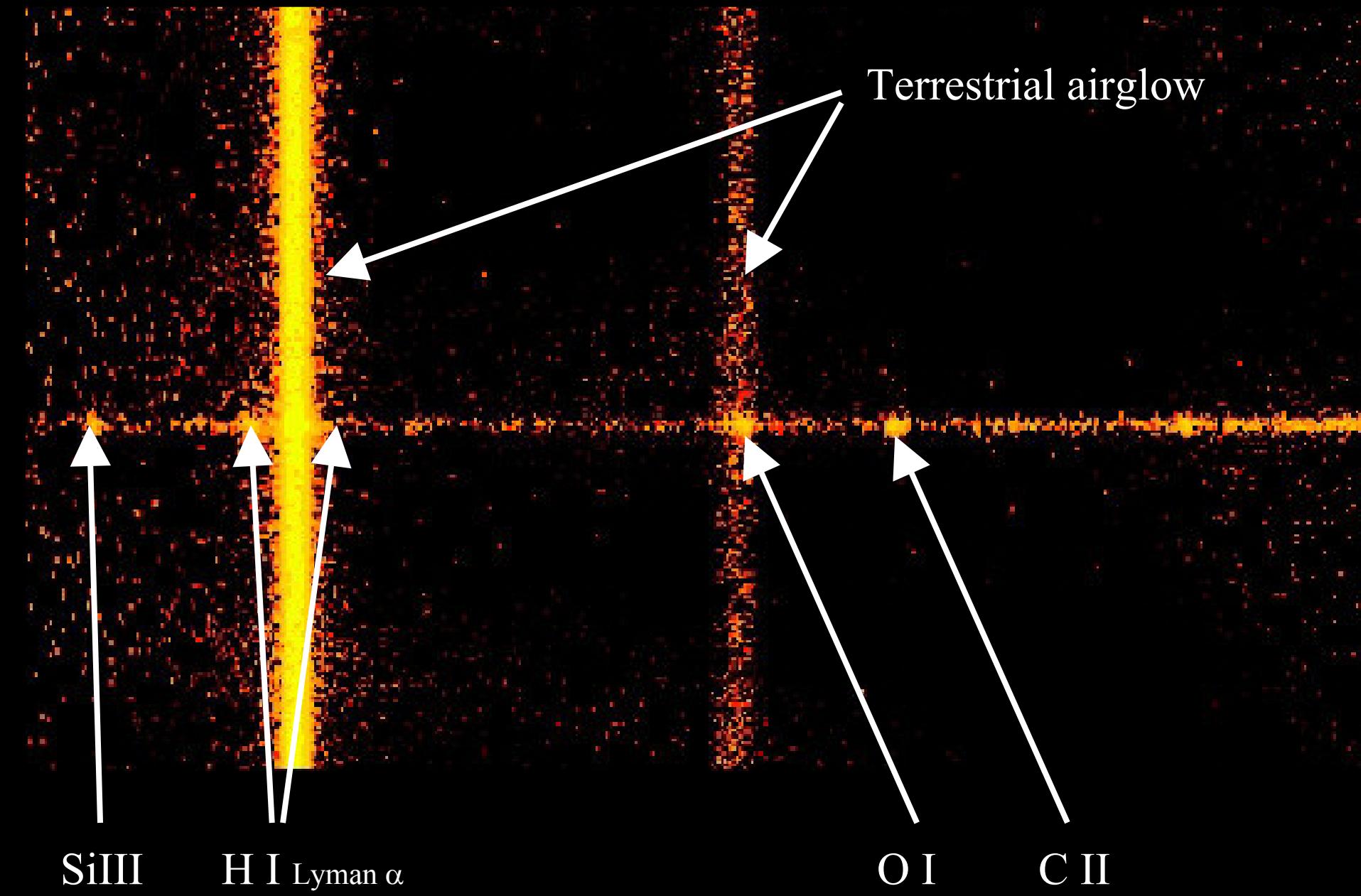
	1 transit	3 transits
Total	70,000	210,000
Airglow	40,000	120,000
Useful (“In”)	300	900
Absorbed during transit	45	135

→ $135/\sqrt{900}=4.5 \sigma$ → needs confirmation

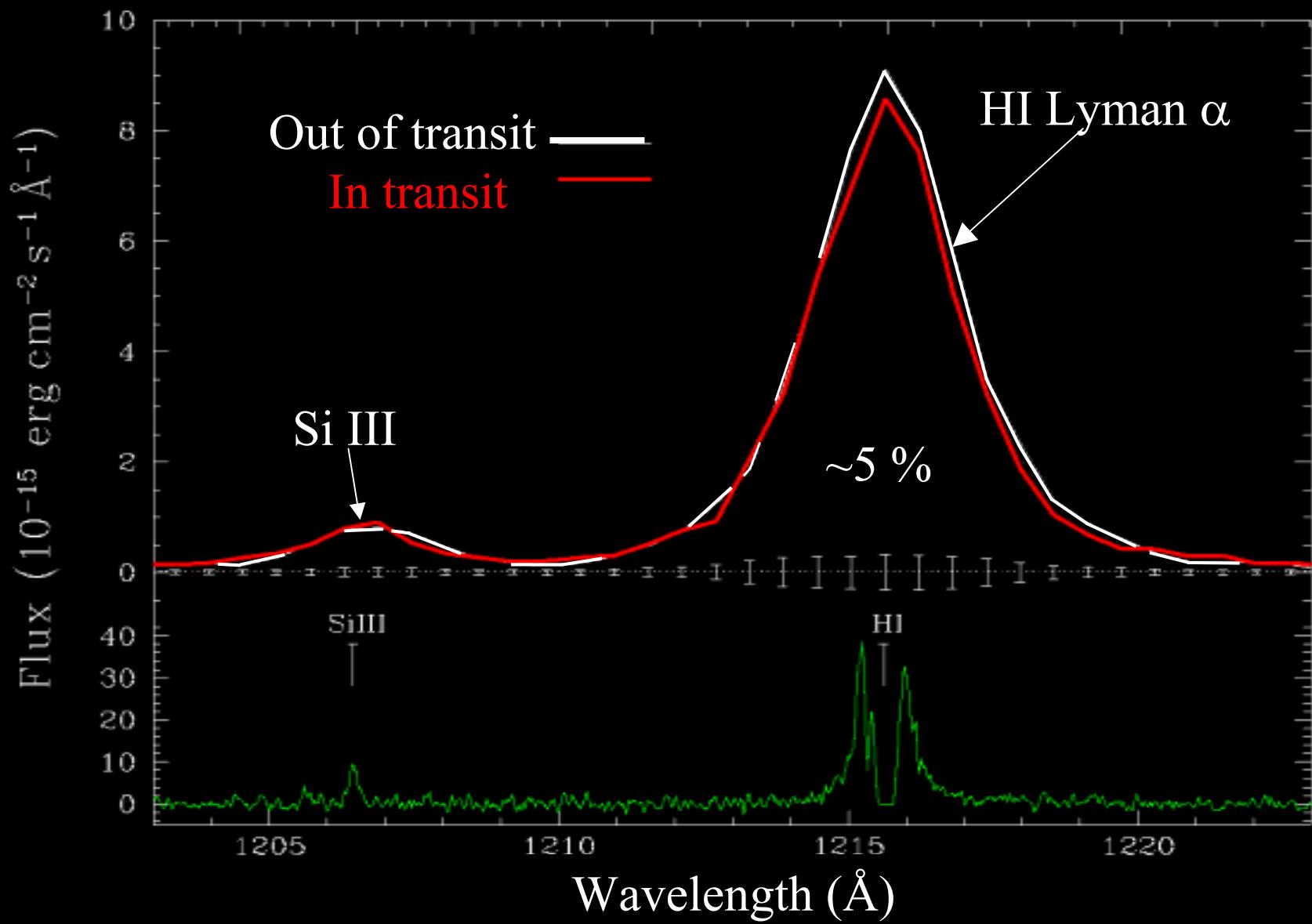
STIS G140L, low resolution observations

Oct-Nov 2003

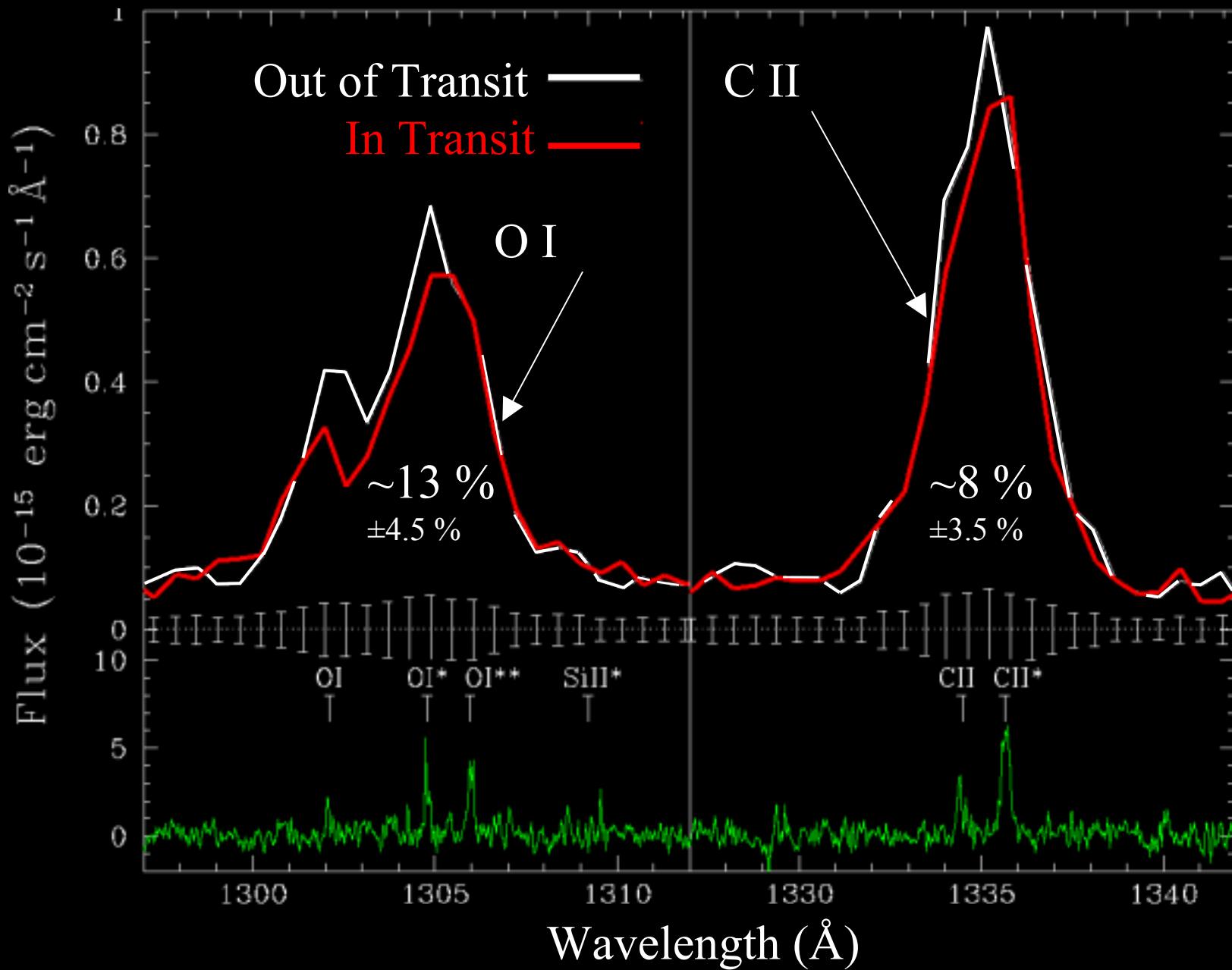




Confirmation of the HI absorption



Detection of Carbon and Oxygen





Consequences

(Vidal-Madjar et al. 2004 ApJ 604, 69)



- Oxygen and carbon are also present in the upper atmosphere of HD 209458b
- They are carried away by the hydrogen flow at least at a velocity of about $V > 10$ km/s
(~ sound speed)



HYDRODYNAMIC ESCAPE
(« BLOW-OFF »)



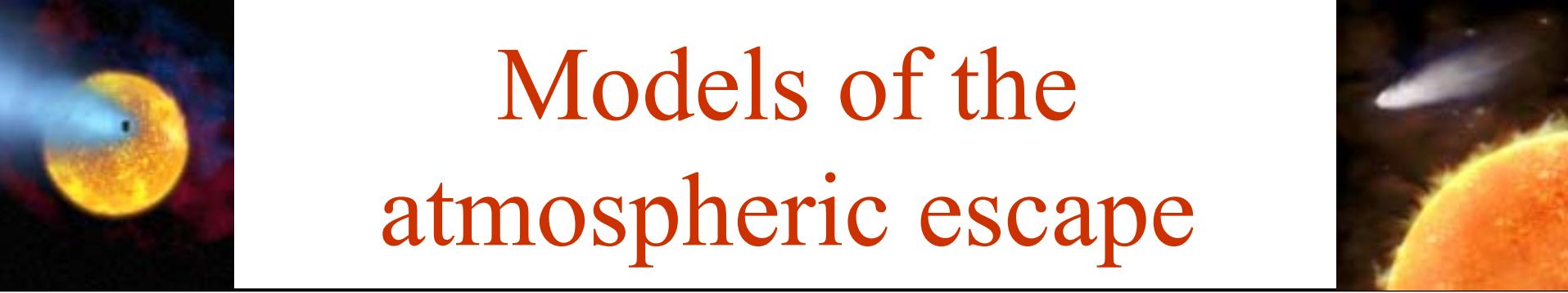
Other consequences

- Presence of OI*, OI** $\rightarrow n \approx 10^6 \text{ cm}^{-3}$ at R_{Roche}
- $n = \tau / (\sigma \cdot L)$ ($L \sim 3 \cdot 10^5 \text{ km}$) $\rightarrow n \approx 10^6 \text{ cm}^{-3}$ at R_{Roche}
- Escape rate: $\sim n \cdot S \cdot V$

where S is the surface of the Roche lobe ($R_{\text{Roche}} = 3.6 R_{\text{Jup}}$)

V is the H, O and C atoms velocity at the Roche lobe level ($V > 10 \text{ km/s}$)

Escape rate $> 1.3 \times 10^{10} \text{ g/s} !!!$



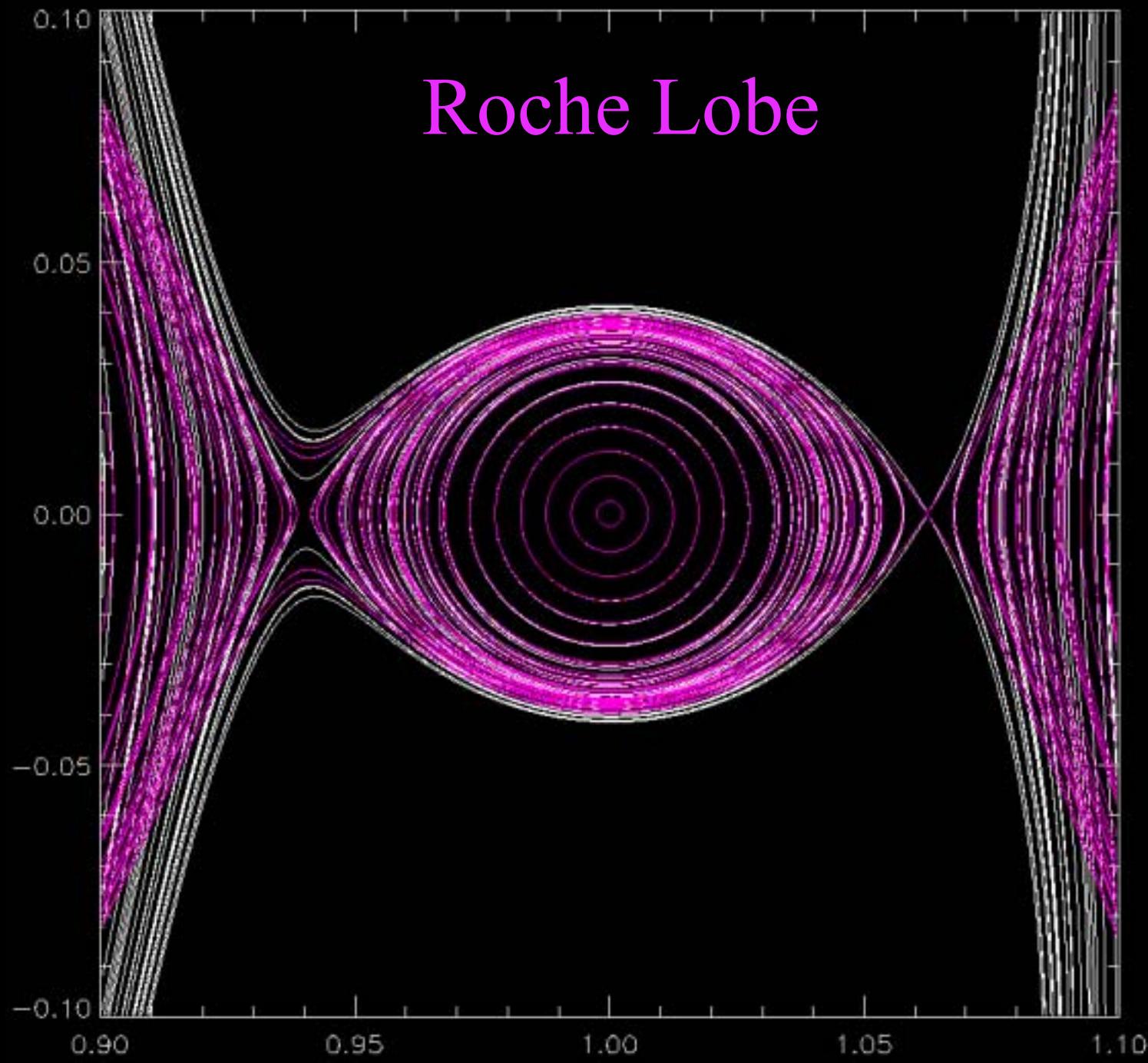
Models of the atmospheric escape

Two important hypothesis:

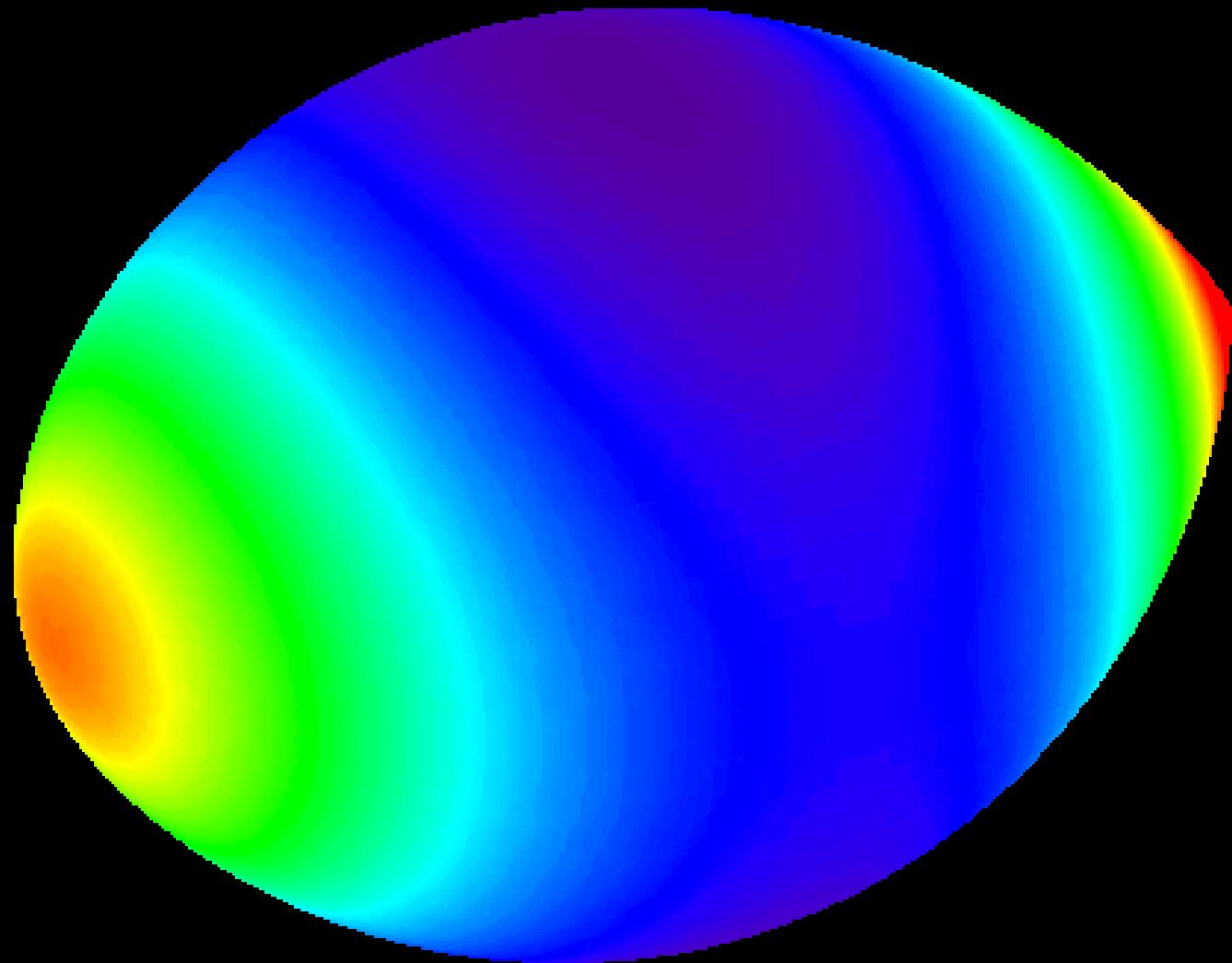
- Temperature of the upper atmosphere: $T_{up} \neq T_{eff}$
Note that $T_{up}(Jupiter) \sim 1000\text{ K}$ is not explained...
- Tidal forces from the close-by parent star

NB: Burrows & Lunine, Nature 378, 333 (1995)
→ Escape(H₂⁺, H⁺, HI) = 10¹⁰ g s⁻¹

Roche Lobe

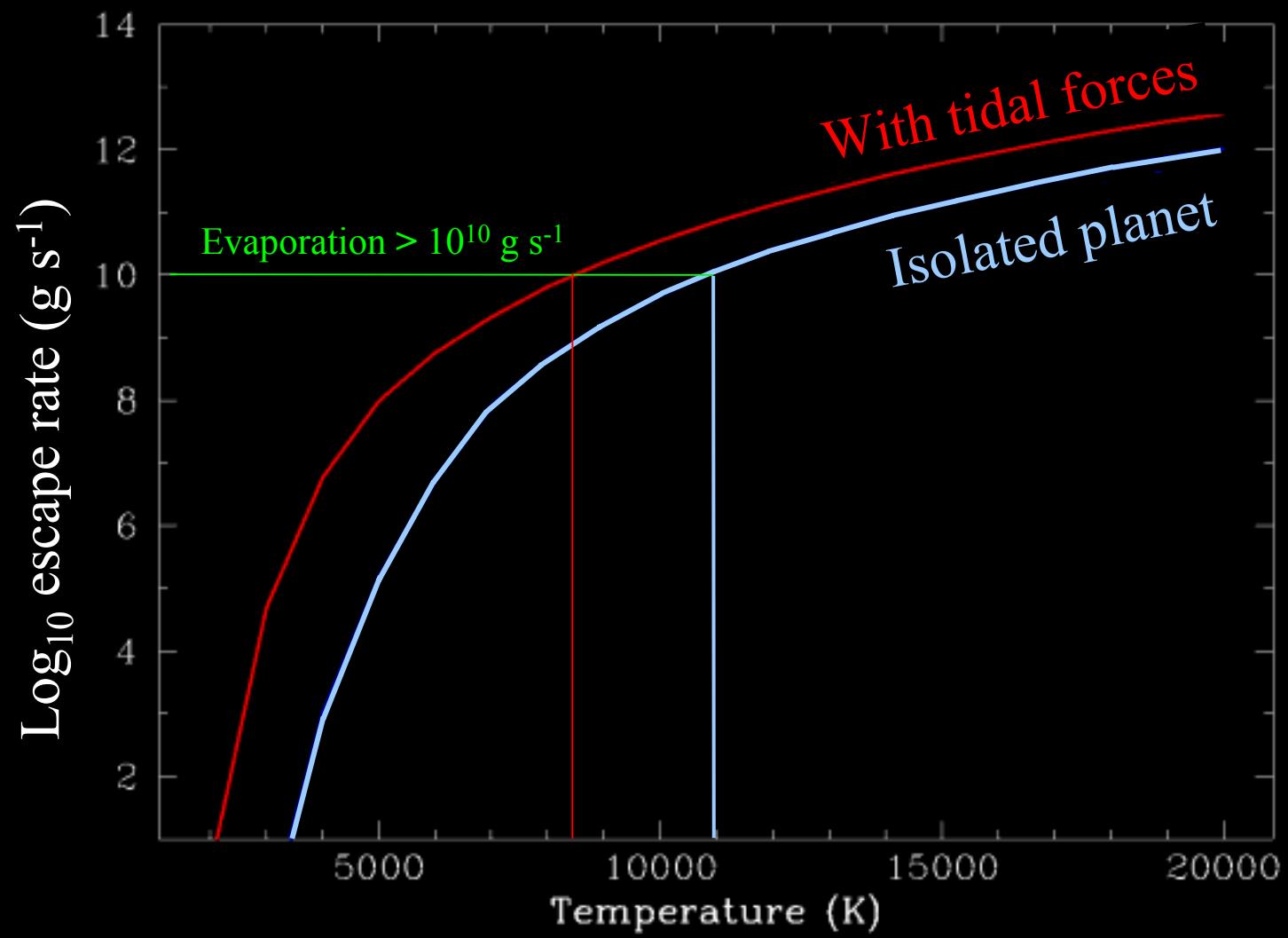


Escape through the exobase



Escape Rate

(Lecavelier et al., 2004, A&A 418, L1)





Temperature of the upper atmosphere

Hypothesis:

Heating = UV ($\text{Ly}\alpha$) + EUV

Cooling

= Thermal Conduction

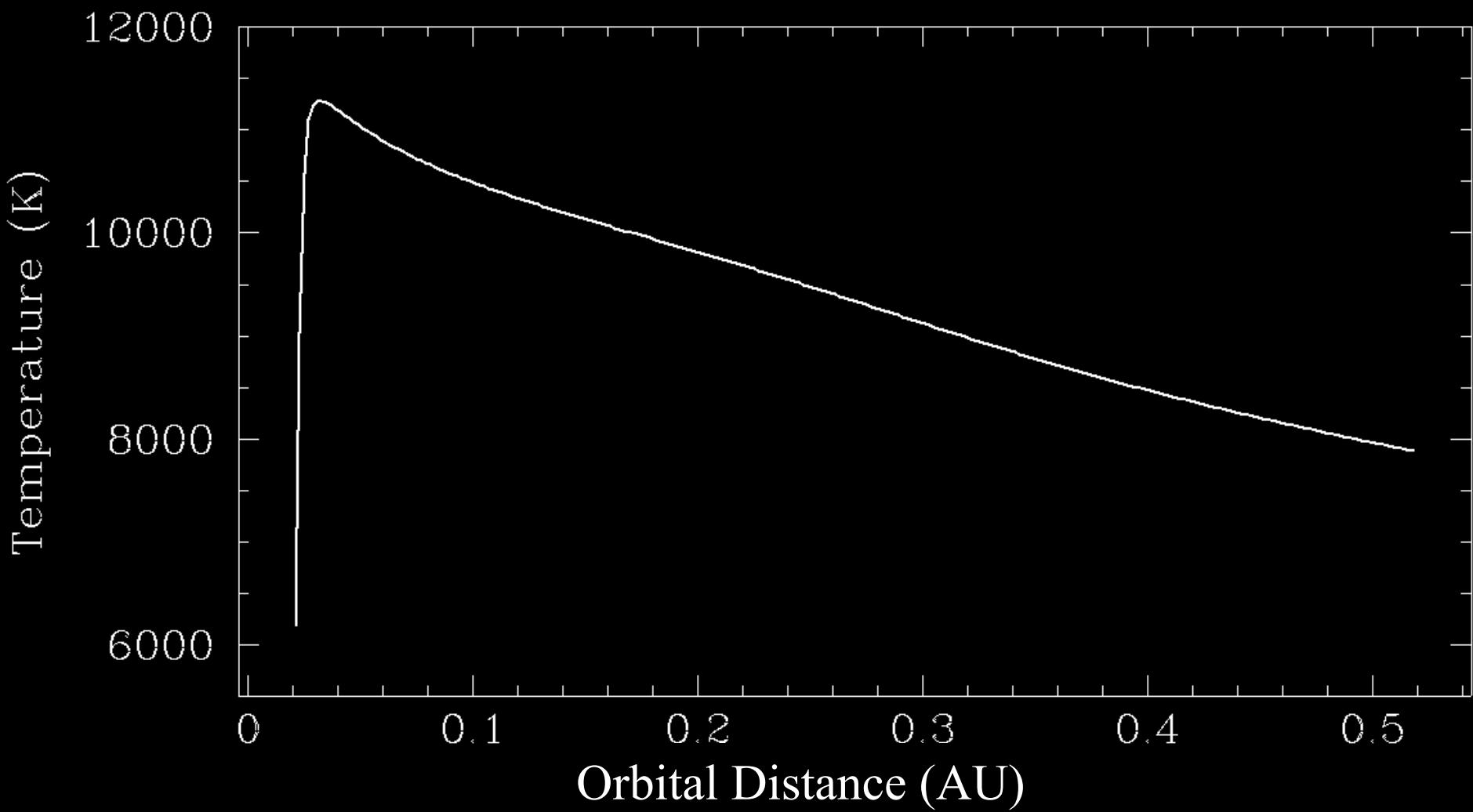
+ Collisional excitation of HI levels

+ Collisional ionisation

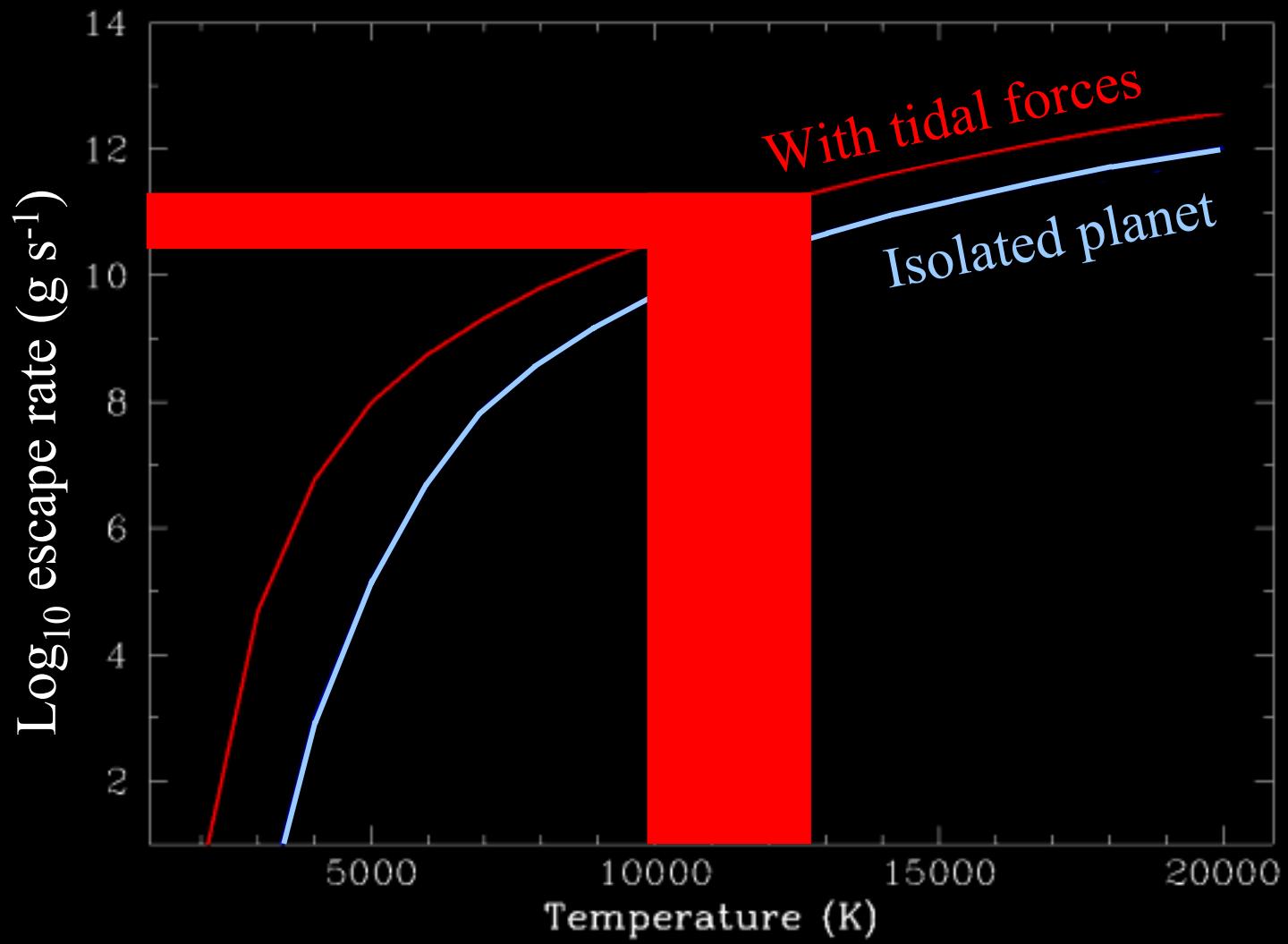
+ Escape



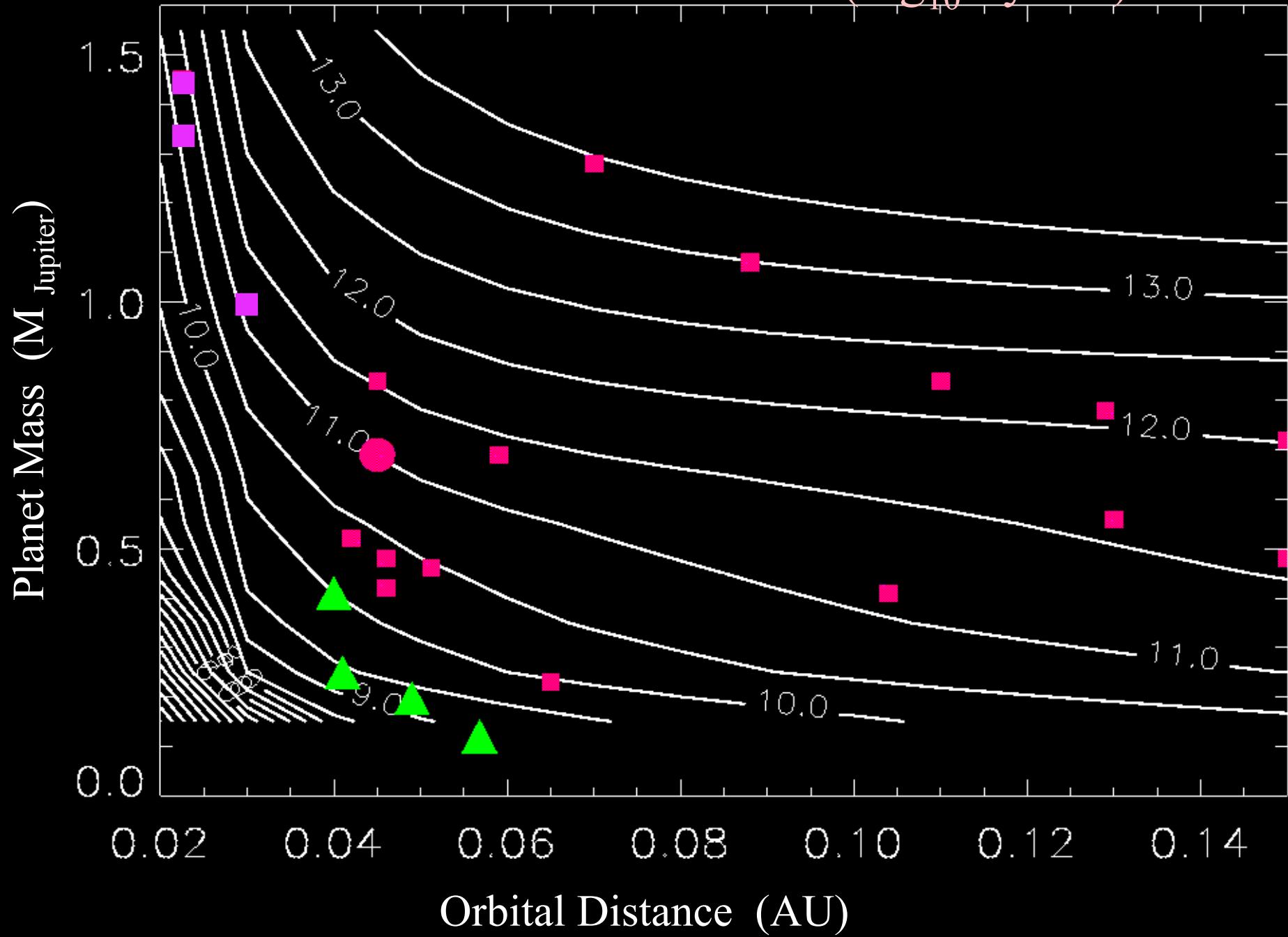
Temperature of the upper atmosphere



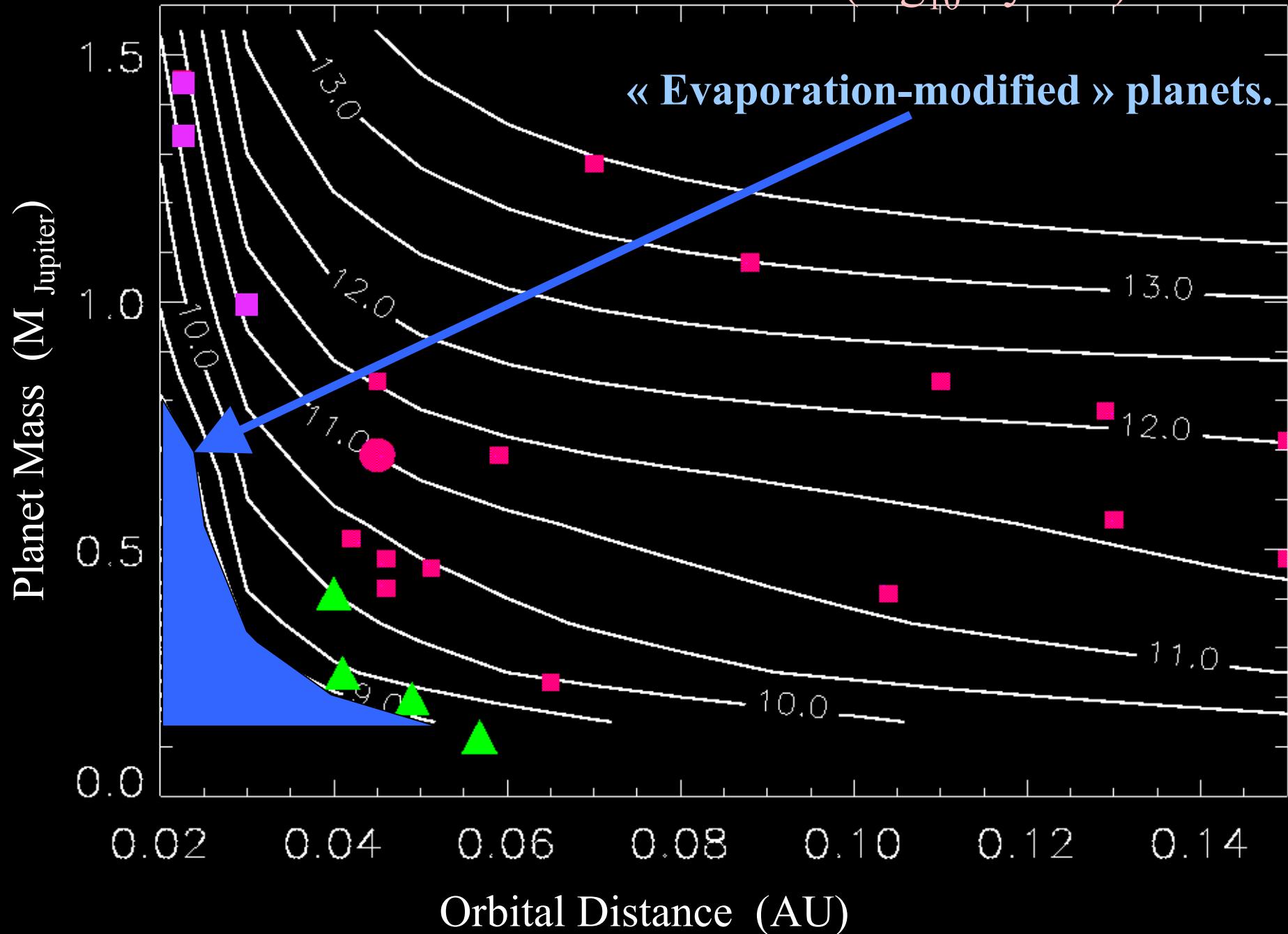
Escape Rate



Planets' Life Time ($\log_{10} t/\text{years}$)



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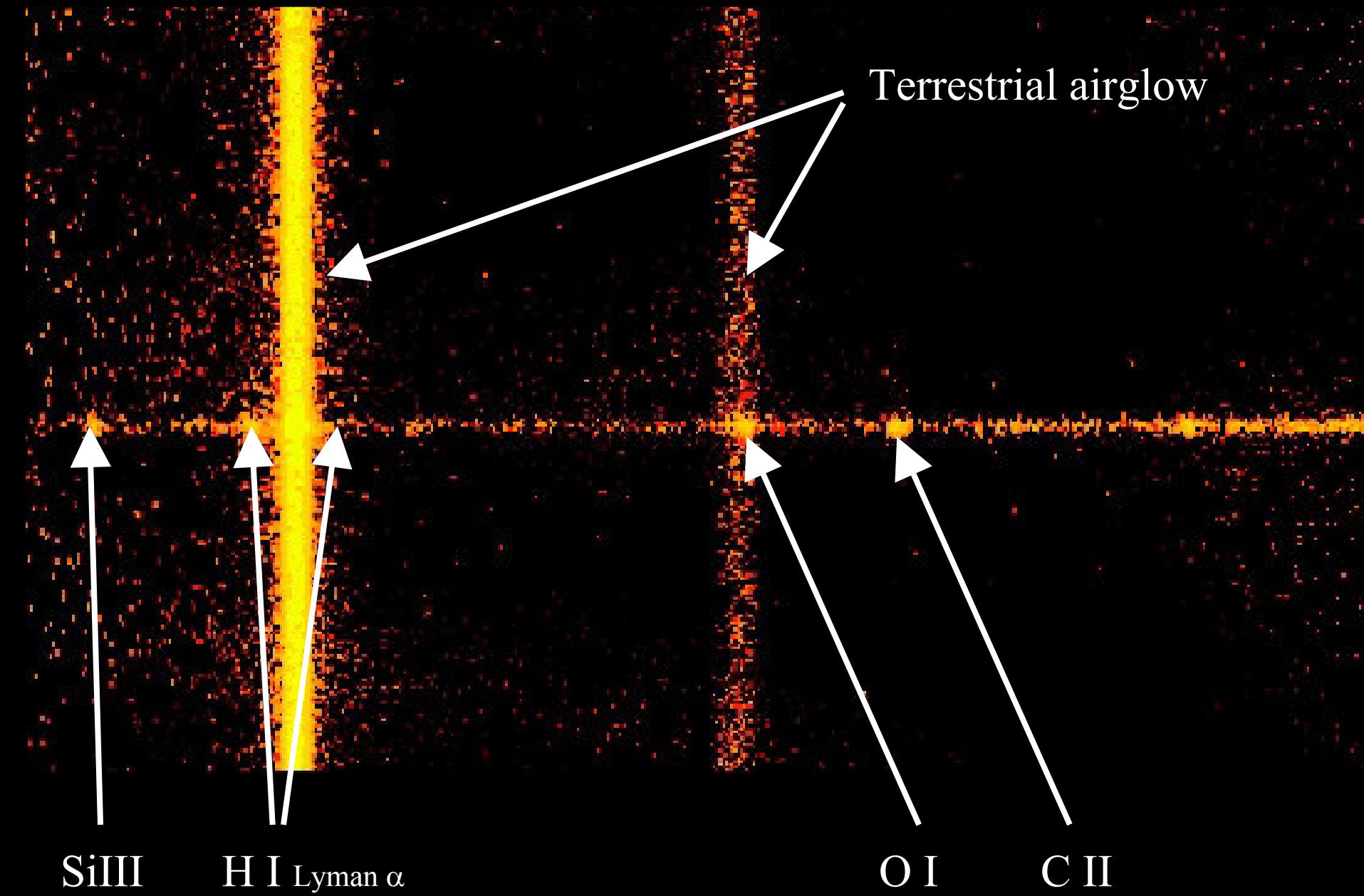


What an High Sensitivity UV-Opt. Spectrograph on TPF-C-size telescope would allow to do?

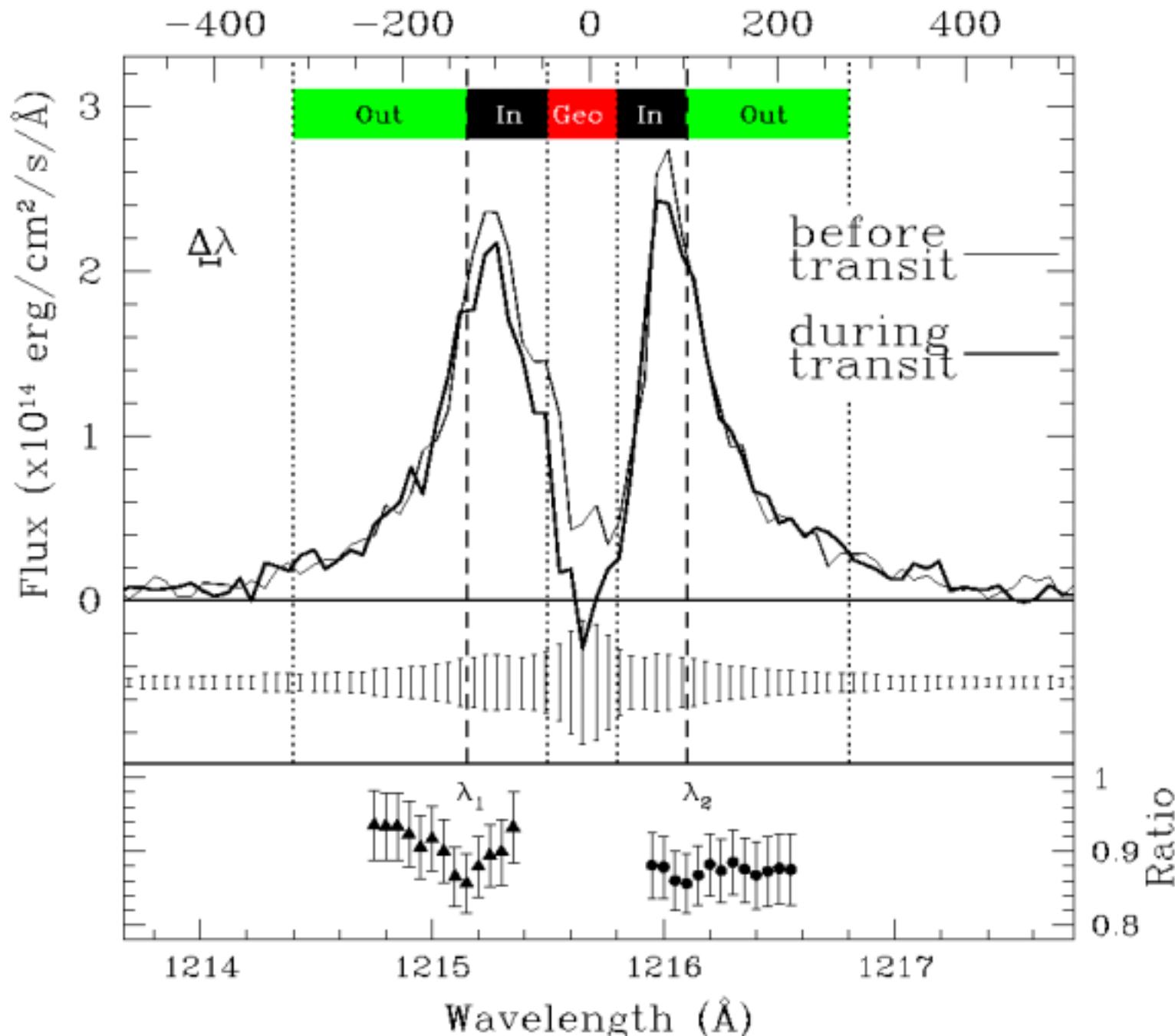
Transits

(NB: 4 detections with HST/STIS in UV-Opt.)

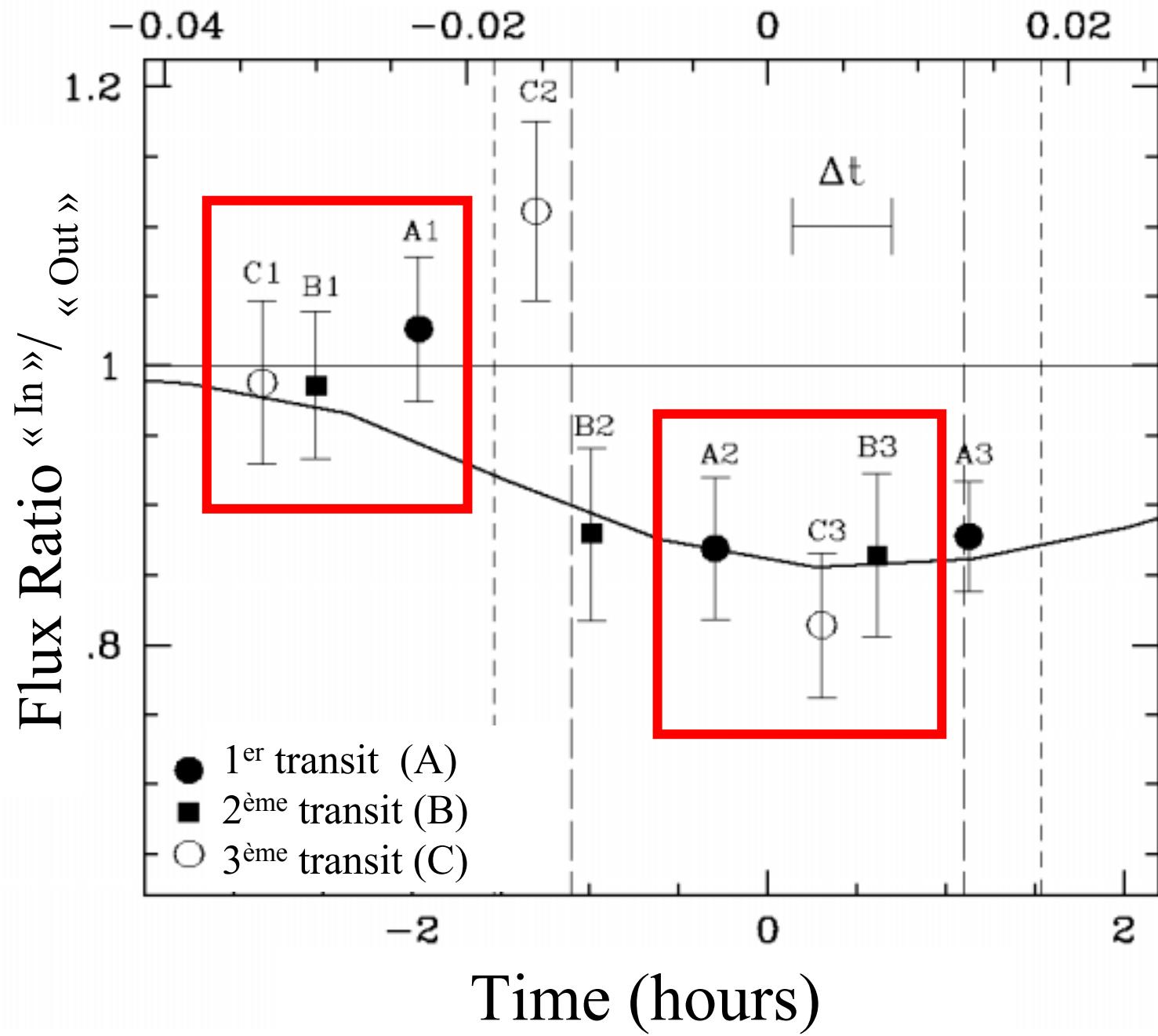
- Targets: Nb: 10-100 targets
Time on telescope : total \sim 1 day /target
Identified by: Gaia & Follow-up of RadVel. surveys
- Species: O₃, O₂, CO₂, CO, H₂O, etc.
- Type of planets: Earth-like planets
Ocean Planet
Satellites of Giant Planets.

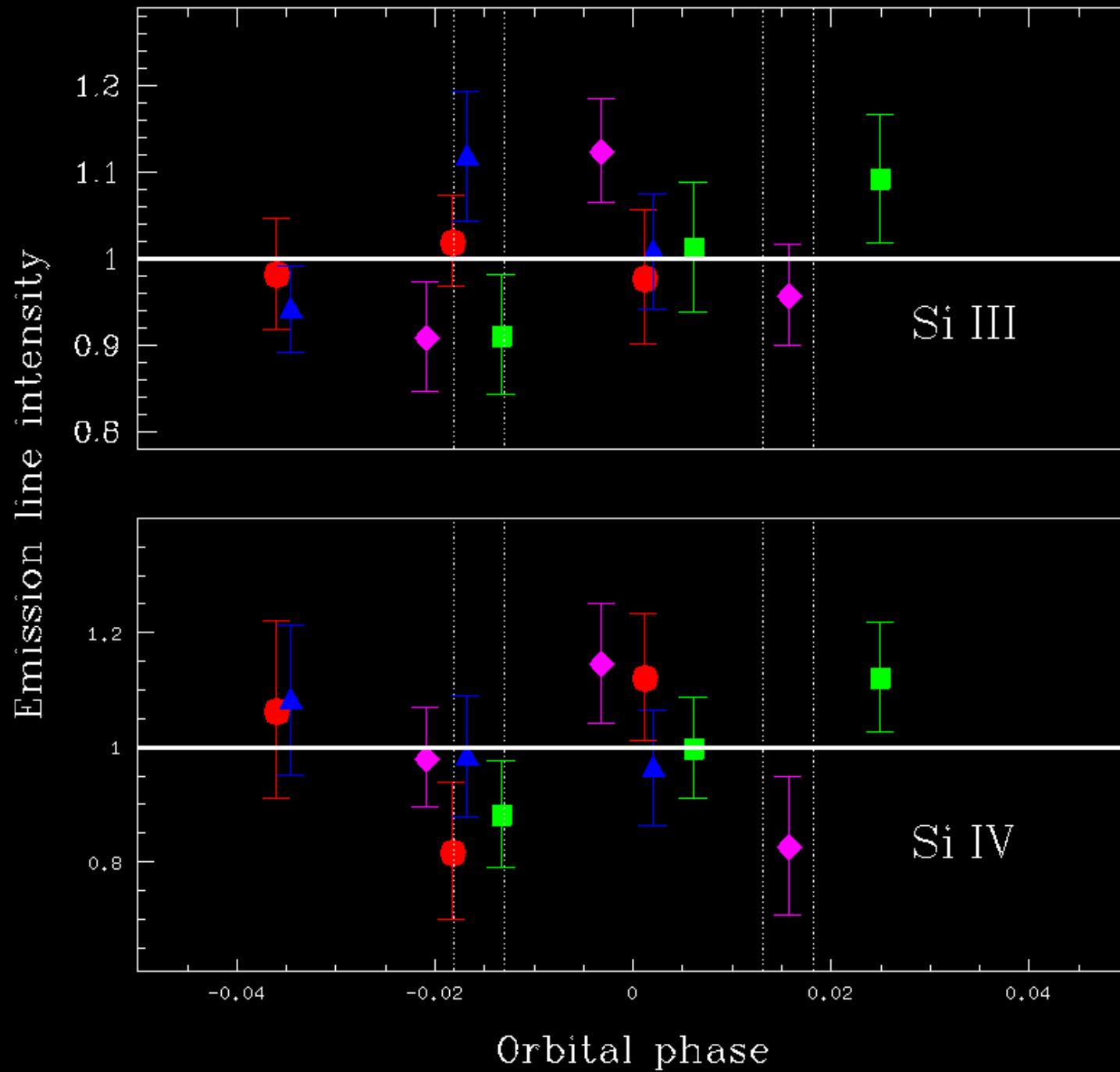


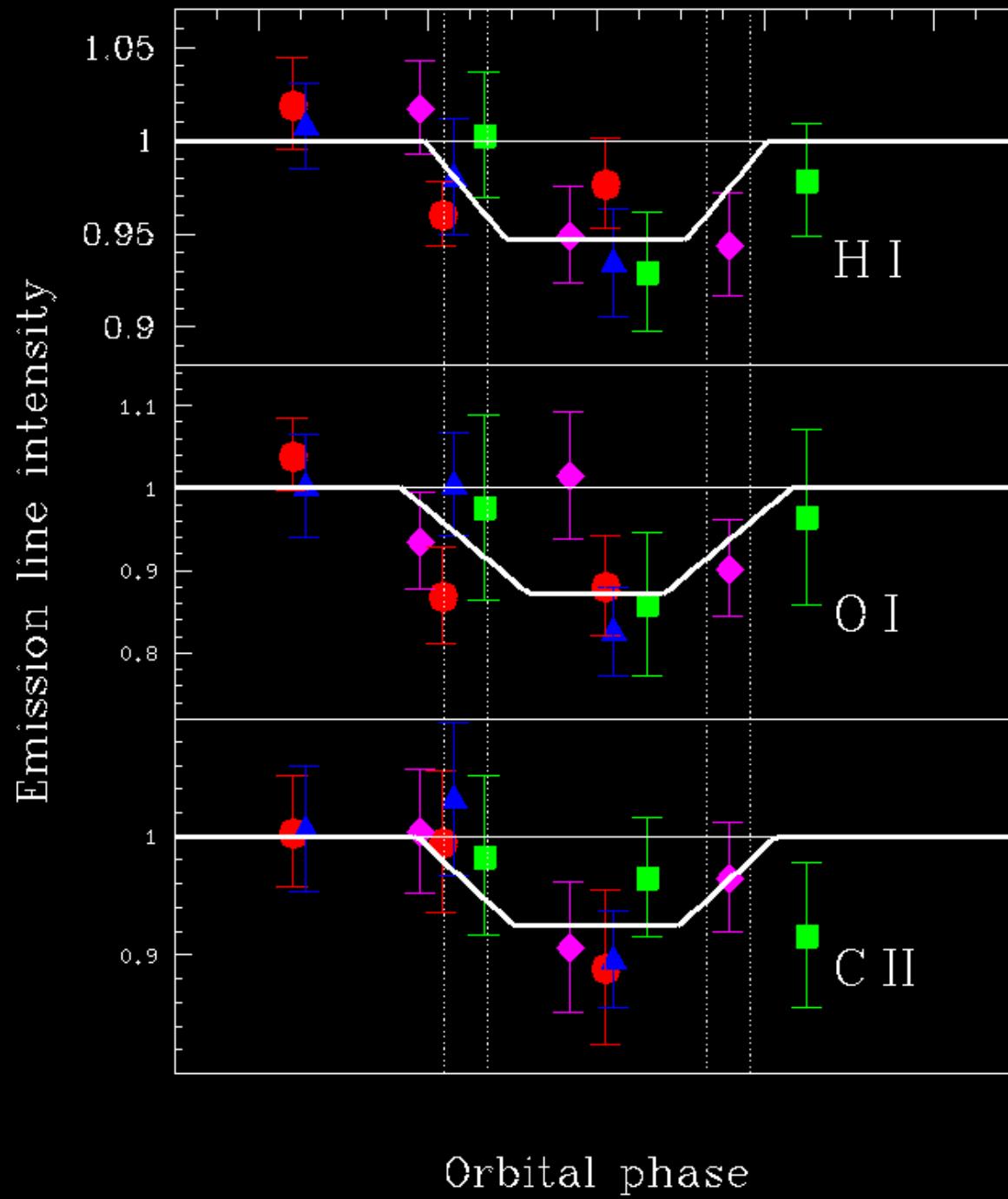
Velocity in the stellar reference frame (km/s)

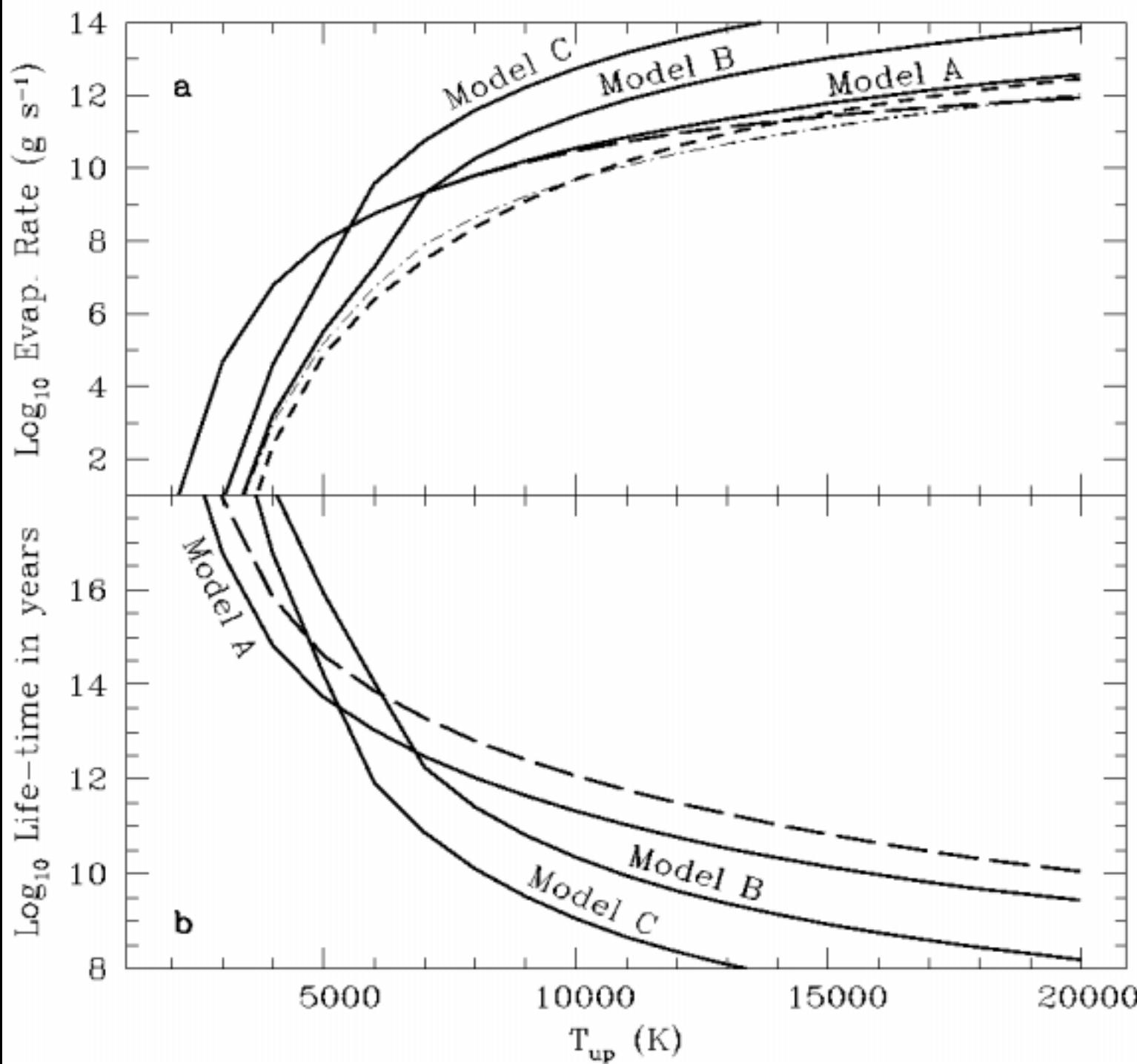


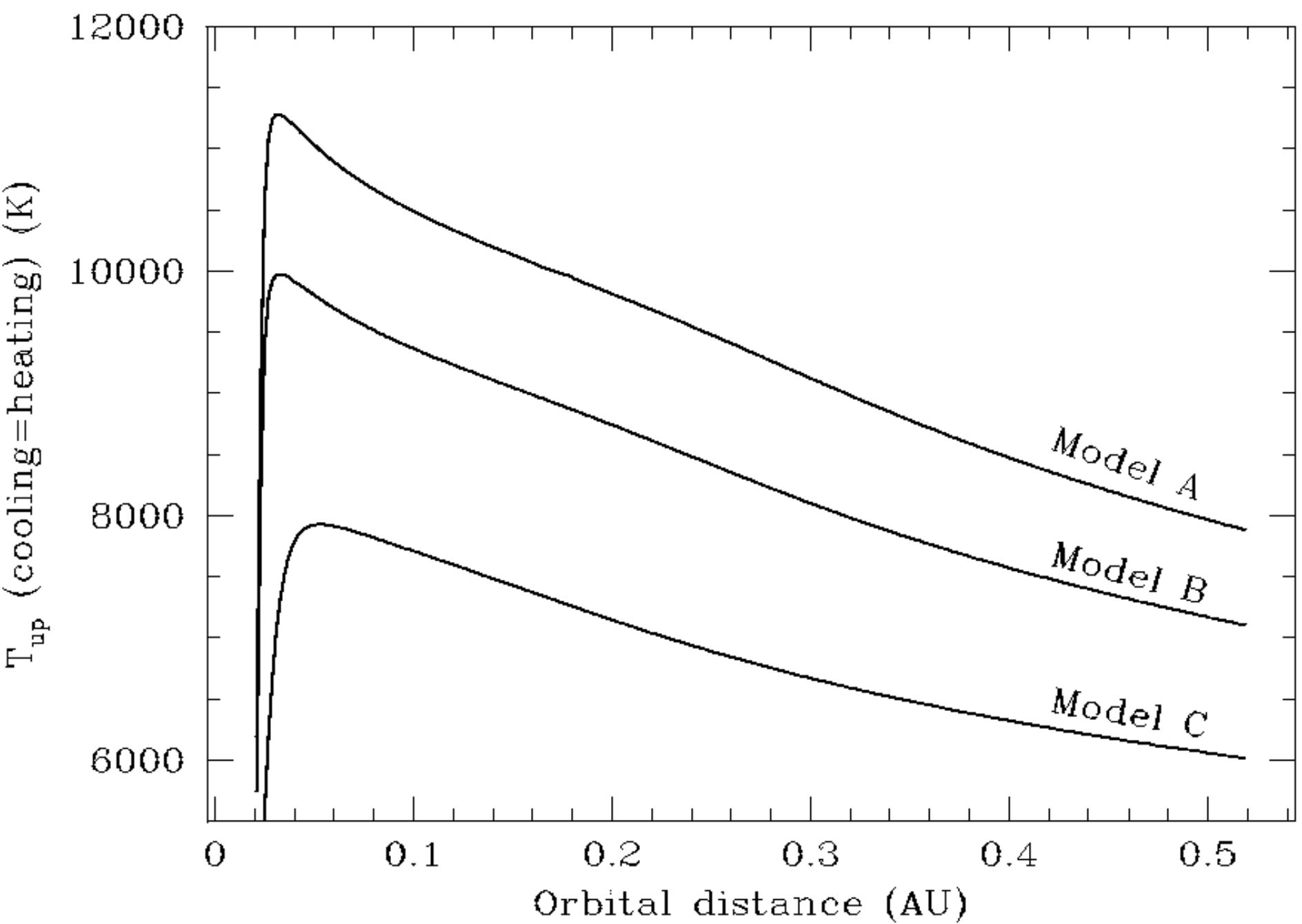
Orbital Phase



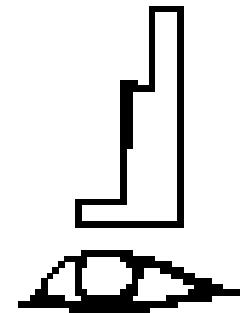








Instead of the name HD 209458 b, why not OSIRIS ?



Osiris was cut into pieces spread all over Egypt by his brother Seth to prevent his return to life...